Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 214 SEPTEMBER, 1932 No. 3

SOME SCIENTIFIC VIEWS TO THE FRANKLIN INSTITUTE ON THE EIGHTEENTH OF MAY 1932.*

BY

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The Franklin Institute has thought approvingly of my old work on cathode rays. I should like to respond properly to the invitation to express myself on this occasion when I state briefly what today appears to me as the most essential result of the views established at that time, and in the course of subsequent considerations.

When I, forty years ago, after the fruitless efforts of an earlier year, had the good fortune for the first time to see Hittorf's "Kathodenstrahlen," Crookes' "Radiant Matter," pass by means of the aluminium-window from the discharge tube into free air, my desire was at last fulfilled to have a new, efficient means of advancing forward into the unknown. To discover anything of the unknown world had ever been my highest desire; indeed anything had seemed wholly wonderful whenever the investigator was able to see more of it than before. The best work of my life began at that time, and I was young enough not to permit any obstacle to frighten me. To be sure, I was also too young to be sufficiently supported by

* Presented at the Medal Meeting held Wednesday, May 18, 1932, by Charles Burton Thwing, Ph.D.

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

apparatus; nevertheless I succeeded in obtaining rapidly results which at once brought a small number of better equipped researchers likewise to the belief which Crookes thirteen years previously had uttered prophetically concerning his radiant matter: "Here lie ultimate realities." No one had attempted to let this mysterious radiant matter pass outside the tube in order to be able actually to observe what it is and how it behaves itself under any conditions, and yet in these questions lay indeed all the knowledge, in part immediately, in part by inference, which constitutes the newer parts of physics.

First and foremost, I succeeded in showing that the rays are not projected atoms or molecules, for they entered into perfectly evacuated spaces in which one had not been able to produce them and took with them nothing of the nature of matter. No trace of gas appeared in these spaces; they remained as empty as originally. Evidently the "cathode rays" were therefore no "radiant matter"; they must be something still more remarkable. It was then shown that they were projected negative electricity. Here for the first time *electricity as such* had been obtained. Previously electricity was known only when on charged bodies or flowing in wires; nobody knew whether it was separable from these material carriers, and was of itself a particular substance capable of being investigated. It was the negative electricity which was discovered in this way. It is today indeed common knowledge that it consists of the small particles, the electrons, as matter is composed of atoms. It is these electrons, therefore, which go out from the window of the discharge tube in the form of rays, with very high velocity.

I was fortunate enough to succeed in showing that the rays pass right through everything which is not too massive, which does not weigh too much. It was very noticeable that the passage of these rays depended only on the weight; transparency or opacity for light was wholly a matter of indifference; for example glass sheets and aluminium sheets which in equal thickness weigh the same showed themselves to be equally pervious to these rays. Such a radiation had not been known before that time, a radiation which governed itself only with regard to weight and mass without any reference to the nature of the material and its state of aggrega-

tion. Today, to be sure, one knows several such radiations; they all have the common quality of extreme minuteness in their composition like the minuteness of the electrons in the case of the cathode rays. Compared with the electrons even the small wave-lengths of visible light are great. When light passes through matter every wave of it covers large groups of atoms; while the small electrons of the cathode rays hit the single atoms, nay, even parts of them so that by means of these rays it became possible to investigate the nature of the atoms and of their parts. From the uniformity of behavior with equal weights the conclusion was to be drawn that all sorts of atoms of matter are fundamentally the same, varying only in different amounts according to the atomic weight. It was soon to be seen that the so indicated common fundamental constituents of all atoms are really the two electricities, the negative electrons and the corresponding elementary quantities of the positive electricity. The cathode rays, the projected electrons, demonstrably went through the interior of the atoms, and they were thereby deflected, as in electric and magnetic fields. Such fields, and indeed fields of extraordinary strengths, were in this way shown to exist in the *interior of the atoms*, and the centres of force of those fields are the two electricities whose presence in the atoms was already likely to be assumed by other reasons. Today the curvilinear passage of cathode rays through thin layers of atoms is investigated by much improved methods; but alas observations of nature are in these days preferably derived from calculations arranged beforehand instead of developing from the observations simple ideas, adapted to the nature of things, and afterwards calculating with them. May this be generally more wearisome than comfortable, still it is the way particularly suited to the search for truth.

If now the electricities and the electromagnetic fields of force were recognized in the interior of the atom, still the question remained, whence come the weight and the mass of the atoms? That the negative electricity possesses inertia, mass, had been definitely shown by the cathode rays. Faraday's self-induction had indicated inertia also in the electromagnetic fields; only it was not clear how this was to be understood, because the fields could not be investigated by themselves

alone, without the electricities. Hasenöhrl first demonstrated this in his celebrated investigation with light in a moved hollow space; it was shown that the electromagnetic fields of light possess mass and that this mass belongs to the energy of the fields. *Energy*, which up to that time was regarded only as a numerical magnitude, here for the first time showed itself *connected with mass*. It was then not difficult to conceive that all energy, not only that of light, must have mass and, likewise, that all energy, not only that of light, must be located in electromagnetic fields, must be electric energy. Therewith the very great amounts of energy which are located in the demonstrably strong electromagnetic fields of the atomic interiors and which became specially evident with the discovery and investigation of radio-activity, are to be considered as endowed with mass and with the corresponding weight. Mass and weight of the atom and correspondingly of all matter were now to be looked upon as the mass and weight of the energy-content of the atoms. Measurements with radio-active pendulums showed, in fact, that the energy of the atom has also the weight corresponding to its mass, that energy weighs something, that it is measurable with the balance. The deflection of the light rays at the edge of the sun showed—so far as it is to be well followed in the always disturbing refraction in the sun's atmosphere—that the energy of light, which is free of matter, underlies gravitation also, that it has also weight corresponding to its mass. Thus mass and weight, gravitation, which earlier were regarded as properties of matter only, are now allotted to energy, and matter is now to be looked upon as an especially concentrated form of energy, as a special case of aggregation of energy.

That the energy in the atoms has its especial laws was clear from Planck's quanta; nevertheless matter with its atoms has now ceased to be looked upon as something fundamentally different from the waves of light, which are also energy. The original conception that light is an æther wave in the same sense as sound is an air wave i.e. that æther particles are oscillating in the light waves had, to be sure, been given up since Faraday's and Maxwell's electromagnetic waves had shown themselves in agreement with the fact. Atoms and

light waves have become in this way fundamentally one and the same, namely forms of energy. This is an even much greater simplification in the aspect of nature than the conception of equality of all atoms in their constituents.

By these considerations, the antithesis between matter and æther is reduced to the vanishing point. According to earlier views, matter and æther were the two sorts of constituents which built up the sensible world capable of investigation; that which was not matter i.e. did not consist of atoms, was to be called æther or belonged to the æther. Now matter is no longer a particular stuff; energy has stepped into this place. Matter belongs to energy as well as the free electrons of the cathode rays, which previously were to be thought of as particles of the æther, and likewise waves of light.

But what then is *the æther?* It is still ever the same as with Huygens, who introduced it as the medium which transmits the light waves; only it does not make and vibrate the waves, but is determinative of the velocity of their propagation or, more generally, of the velocity of propagation of electromagnetic fields. This velocity, the velocity of light, has—like every specification of velocity—sense and definite significance only when we know to what it is referred, i.e., if we are told where the measuring road is fixed on which the distance passed over in a given time is measured. Sound has its known velocity relative to the air in which it travels, not relative to the ground; the latter would be the case only if the air were at rest relatively to the ground. Just so, light spreads out with its known great velocity relatively to the æther in which it travels. Thus æther can in agreement with present day knowledge be best defined as that something which in the manner indicated is determinative of the velocity of propagation of light. The velocity of light is not an accidental thing and indeterminate; therefore, there must be in space something determinable relative to which it is to be considered, and this something is the æther. The æther defined in this manner must be at rest in reference to the earth, according to the conclusions of Michelson's famous experiment; the earth has therefore its own æther and takes that æther along with itself in its movement through the heavenly spaces. The æther need not however participate in the earth's rotation;

this is a particular question the solution of which can only be gained from continued experience. But it is not indeed to be doubted that like the earth also every other star has its own special æther resting on it; definite observations on double stars have shown that the particular æther of the stars becomes unnoticeable at great distances from them, and passes over into a general æther "Uræther," which might indeed be the sum of all the slight parts of the æthers of the remote, surrounding stars. But if great and small stars have their own particular æthers, so must also every piece of matter have its proper æther. Going even further, according to the view obtained concerning matter as a special case of energy, it is to be accepted that quite generally *every amount of energy* of whatever sort *has its own associated æther* which always accompanies it and surrounds it as an envelope, with an attenuation extending to great, even infinite distance.

This new conception appears to ascribe to the æther an especial role; it lets it, the æther, appear as the active agent of *gravitation*. In fact it is true, as we saw, that weight, gravitation, is an attribute not only of matter, but of every amount of energy, and gravitation extends, according to Newton's law, out to infinity. In fact, by means of gravitation every amount of energy is everywhere like every atom; gravitation fails at no distance, and this objective omnipresence of all the energies of the world may lie in the presence of their æther envelopes.

Not æther and matter do therefore make up the Universe, but *æther and energy*, and these two do not stand in opposition to each other, but belong always and inseparably together; to every quantity of energy belongs its æther.

Hence, the Universe now appears to me to be represented in bold strokes, in accordance with all known facts, a little otherwise than forty years ago. At that time *every element with its atoms* appeared as something peculiar of its own, in spite of known periodic similarities; transmutations of the atoms appeared as remote as at the time of the lasting disappointments of the alchemists. *Energy* was in spite of the certainty of its constancy and its great importance only a magnitude of reckoning; to look upon it as a substance, to scrutinize its spatial distribution and its wanderings in space

appeared senseless; it had no other property than its constancy as a magnitude of reckoning. *The æther* appeared homogeneous, filling the whole of space, almost identical with space itself; at most, one sought some mechanism in it instead of avowing at once as we do now, that it is throughout peculiar to itself, and not to be investigated after the manner of any material analogy, that it stands much nearer to the world of spirits and souls than to any sort of mechanism.—

The Franklin Institute may also after forty more years' or indeed earlier, be advised what at that time will have been changed in our knowledge of the Universe—if at all one then still seeks for reality and does not satisfy himself with two, three or more "theories" which all contradict each other, and yet all want to be correct.*

* For further information on the subjects treated here, the following publications by the author may be consulted:

"Über Kathodenstrahlen" (Gruyter, Berlin, 1920);

"Über Aether und Uraether" (Hirzel, Leipzig, 1922);

"Über Energie und Gravitation" (Gruyter, Berlin, 1929);

"Grosse Naturforscher," pages 316–320 (Lehmann, München, 1930).

Tung Oil—A New Southern Industry.—(*Ind. and Eng. Chem.*, 24, 687.) A very interesting story of how *Aleurites fardii* (Tung Oil Tree) came to America is told by H. A. Gardner. For thirty years the American paint and varnish industry has secured all its tung oil from the Yangtze Valley and other regions of China. Within a relatively few past years over 20,000 acres of trees have been planted in this country which, within a few more years, probably will have increased from 50,000 to 100,000 acres.

Tung oil is a fatty oil and as such may be compared to other vegetable oils such as linseed, olive and palm oils. However, it differs in consisting principally of the glyceride of eleostearic acid. This acid is a singularly reactive substance and is responsible for the several desirable characteristics of the tung oil. In its natural state in the cells of the tung nut seeds, the oil is practically colorless and neutral in reaction and when removed by cold pressing as practiced in America, it is light in color. The best quality of China oil is of a darker color and may contain up to 7 per cent. free acid.

Aleurites fordii is the particular variety of tung oil tree best suited to the American climate. It grows from 20 to 25 feet in height and is low-branching in growth habit. The leaves are deciduous, large and dark green in color, more or less heart-shaped. The flowers, produced before the leaves, are white with pink centers and yellow stamens on the male blossoms. The fruit is about the size and appearance of a small russet apple, being first a dark olive green turning to a deep brown as it ripens. Tung oil, besides its principal use in varnishes and varnish paints, also is used in making insulating compounds; as an ingredient in automobile brake linings; in gaskets for steam pipes; in linoleum and table oilcloth; for waterproofing fabrics, paper, cartridge shells, etc.; as a binder for wall board and plastic synthetic lumber; for lacquers, primers, pipe-coating plastics, synthetic resins, battery jar compounds, airplane-tubing fillers, etc. Twenty-five years ago a decided improvement in the quality of varnishes was accomplished by using tung oil with esterified rosin. Such varnishes possess very desirable properties some of which never have been superseded by the newer cellulose lacquers. Tung oil also is an essential ingredient of many quick-drying varnishes and as such will probably enjoy an increasing demand for several years to come.

C.

ASTRONOMERS AND THEIR TELESCOPES.*

BY

AMBROSE SWASEY, D.Eng., Sc.D., LL.D.

It is but natural for one along in years to think and speak in retrospect, and what I have to say on this occasion relative to astronomers and their telescopes will be reminiscent in a large degree.

May I first speak of Worcester Reed Warner, who was a close friend and associate from the time we met in my native town of Exeter, New Hampshire, until his decease in 1929, covering a period of sixty-three years. Although for half a century our work in building engines of industry was of much greater volume than building engines of science, I am pleased to say that the opportunity of cooperating with men well versed in the science of astronomy was a rich experience which we greatly prized.

The first refracting telescope in this country was made by Dollond, a noted instrument-maker of London, and was installed at Yale College in 1830. Although for fully 200 years previous to that time many telescopes had been made, it was the genius and skill of Alvan Clark, a portrait painter of Cambridge, Massachusetts, that brought the lenses of such instruments to a higher state of perfection than ever before attained. In later years, Mr. Clark was joined by his two sons, George and Alvan, who also devoted their lives to this work, and the fame of this firm spread not only through this country, but throughout the world. Beginning with objectives of smaller diameters, as the years went on they made larger object glasses from 20 inches up to 40 inches in diameter.

Dr. John A. Brashear, the noted scientist, also devoted a large portion of his life to the building of astronomical instruments and among others he made the 18-inch objective for the University of Pennsylvania, the 20-inch for Chabot Observatory, Oakland, California, the 22-inch for Swarthmore

* Presented at the Medal Meeting held Wednesday, May 18, 1932.

College and the 30-inch photographic objective, as well as the mounting for the Allegheny Observatory at Pittsburgh. This splendid instrument, of the very highest type in every respect, may well be called the crowning scientific work of my good friend.

Here, in the home of those great scientists and engineers, Franklin and Rittenhouse, it seems eminently proper to mention the work of Professor Charles Leander Doolittle, the Director of the Flower Observatory of the University of Pennsylvania. As many of you know, Professor Doolittle was one of the outstanding astronomers of his day and with his 18-inch refracting telescope and other instruments, his observatory was admirably equipped for carrying on his work. One of the instruments to which he had given a great deal of thought and attention was the reflex zenith telescope, which was somewhat similar to an instrument made in 1836 under the direction of Sir George Airy, Astronomer Royal at Greenwich, the story of which reads like a romance of science.

Because of the special construction of his reflex zenith tube, as it was called, the Astronomer Royal was confident that he could obtain more nearly accurate determination of the positions of certain stars than was possible with any of the instruments that had been devised. After using it for a number of years, he found that the results of one period did not conform to those of another, and the instrument appeared to be so unsatisfactory that work on it was given up, and it was set aside as a complete failure.

Upon the report of a German astronomer made about 1886 that the latitude of his observatory was changing, Dr. Seth C. Chandler of Harvard Observatory made a series of observations relative to this discovery. After comparing his results with those of others, Dr. Chandler came to the conclusion that the pole of the earth revolves in a more or less varying fashion. Theorists, among them the renowned Professor Simon Newcomb, said the pole could not possibly revolve in this fashion. Dr. Chandler, by renewed efforts, tirelessly investigating the observations of others, as well as his own, was able to show to the satisfaction of astronomers that his results were correct. Many instruments entered into this in-

vestigation, including the meridian circle, the almucantor, and the zenith telescope.

Professor Doolittle labored assiduously on this problem and his observations with the reflex zenith telescope, and his deductions during the years succeeding 1896, amply confirmed the conclusions of Professor Chandler, that the earth's pole actually shifts about with a variation of nearly thirty feet from either side of a normal position, and he believed that a single foot could be detected in the movement of the pole. In the words of Chandler "Airy builded better than he knew," and like many other great men, did not live to see his work completed.

In 1869 the firm of Alvan Clark & Sons was commissioned by the United States Government to construct a refracting telescope with an object glass of 26 inches in diameter for the United States Naval Observatory at Washington. It was with this instrument that Asaph Hall, professor of mathematics, in 1877 discovered the two satellites of Mars.

About the same time, a duplicate of the Naval Observatory telescope was ordered from the Clarks by Leander McCormick for the observatory bearing his name at the University of Virginia, the instrument being erected a few years later by Professor Ormond Stone, the director of the observatory. The present director is Professor Samuel A. Mitchell, who with his characteristic perseverance and his powerful telescope, has greatly increased the number of known stellar parallaxes.

It seems almost incredible that the minute distances between the tiny images of the stars on the photographic plate can be measured with such exactness that the astronomer is able to ascertain with a considerable degree of accuracy the great distances to the stars.

In order that we may have a clearer understanding of such distances, some one has estimated that a spider web, such as astronomers use in connection with their instruments for measuring the positions and motions of the stars, of sufficient length to go around the earth's equator, would weigh one pound, and such a web long enough to reach the nearest star—Alpha Centauri, in the vicinity of the Southern Cross, would weigh five hundred thousand tons.

In 1874 James Lick gave $700,000 to a board of trustees to provide a telescope "more powerful than any yet made" and "a suitable observatory connected therewith." In the discussion of this project, the question arose as to whether the new instrument should be a reflector or a refractor. The world's work in astronomy up to that time had been done mainly with refracting telescopes, not because of any inherent superiority in the latter, but because of the mechanical difficulty incident to supporting the great mirror of a reflecting telescope so that it should retain its figure in all positions. After considerable investigation by Professor Newcomb, Professor Holden and others, a refractor was decided upon, and a 36-inch objective was ordered from Alvan Clark & Sons. This was not only the largest refractor that had been built up to that time, but the first to be adapted for the triple purpose of visual, spectroscopic and photographic work.

It was also the first telescope to have its location selected with reference to favorable atmospheric conditions. In 1879, Mr. S. W. Burnham, who had already attained a high position in the astronomical world by the remarkable skill shown in his observations of double stars, was invited by the Lick Trustees to bring his telescope to Mount Hamilton for making observations to assist in determining whether it would be a suitable place for the observatory. The results of these observations were most satisfactory, and as a consequence, Mount Hamilton was definitely decided upon as the site for the observatory.

Professor Edward S. Holden, a graduate of the United States Military Academy, was chosen to be the first director of the Observatory. Of his selection of assistants, Professor Newcomb wrote:

"I know of no example in the world in which young men, most of whom were beginners, attained such success as did those whom Holden collected around him. The names of Barnard and Campbell immediately became well-known in astronomy, owing to the excellence of their work. Burnham, of course, was no beginner, being already well-known, nor was Keeler, who was also on the staff."

The Lick Observatory was fortunate in the selection of Professor Keeler as second director, who had served in the

capacity of astronomer from 1888 to 1891. During this period plans were made for the first great spectroscope to be constructed for the study of radial velocities; this instrument was completed about a year later.

An interruption of his work at Lick occurred when he accepted the directorship of the Allegheny Observatory, the position being available because of the appointment of Professor S. P. Langley as Secretary of the Smithsonian Institution. Professor Keeler held this position at Allegheny until the death of Professor Holden in 1898, when he returned to the Lick Observatory as its second director. One of the early questions that was called to his attention concerned the 36-inch Crossley reflector, which had been presented to the Observatory by Mr. Crossley of Halifax. Inasmuch as the newly acquired reflector did not especially appeal to the members of the staff, Professor Keeler decided to use it himself in photographing nebulæ, and thus proved it far superior to other instruments for this purpose. The photographic plates showed countless nebulæ in every part of the sky, which the human eye was incapable of discerning in the most powerful refracting telescopes. After a year of unremitting labor with the reflector, he gave to the world the most magnificent photographs of nebulæ ever produced. At the time Keeler began his work on the Crossley reflector, only twenty-four spiral nebulæ were known to astronomers; however, by means of this telescope several hundred were discovered.

One might say that at this time the Lick Observatory was counted as the supreme court in all problems pertaining to astronomy since it had in its possession the 36-inch refractor. In addition, it had the 36-inch reflector, which was then the largest reflecting telescope in this country.

Professor Barnard's first assignment was in connection with the 12-inch telescope. Later he was given part time on the 36-inch refractor, which he especially appreciated. On the eleventh night of his observation with the great instrument, he discovered the fifth satellite of Jupiter, after a period of nearly three hundred years since Galileo discovered the first four. Since Professor Barnard's discovery, four additional satellites have been discovered, three at Lick with the Crossley reflector, and one at Greenwich Observatory. Pro-

fessor Barnard applied photography to the study of the heavens with remarkable success, particularly with reference to photographs of the Milky Way and comets.

The time came when Lick was again to have a new director, and good fortune brought Dr. William Wallace Campbell as its head. His work on radial velocities with the 36-inch refractor brought fame to the observatory and to our country. Because of his notable achievements in the realm of astronomical science he is appropriately called the dean of American astronomers.

But the story of the observatory at Mount Hamilton goes on and on. Dr. Campbell is now Director Emeritus, and his home, given to him for life, is on his much loved mountain where he worked so long. Professor Robert G. Aitken is its new Director. His work on double stars has been recognized both here and abroad and for this he is this year to receive the gold medal of the Royal Astronomical Society.

In 1893 the United States Naval Observatory moved to a new location in Washington. Several important new instruments were constructed, among them the 6-inch meridian circle, made entirely of steel, and the 5-inch alt-azimuth. A special observatory building was erected for the 26-inch objective with its new mounting, similar in design in many respects to that of the Lick.

Notwithstanding all that astronomers have said and done, it is to be expected that there are many people who are not familiar with the starry heavens. On the way to Panama a few years ago, rather late one evening when there were few people on deck, I wandered out aft and as it was a very clear night, and the stars were shining brightly, my attention was attracted to the pole star as it was creeping down in its altitude from day to day. As there was but one man out there, leaning on the rail and peering toward the north, I said to him, "The North Star is pretty low tonight, isn't it?" and he turned, and said, "Yes, does that mean we are going to have a storm?"

Let us now turn to Chicago where young George Ellery Hale built the Kenwood Observatory for his study and pleasure; it proved to be a blessing for all. This observatory with its 12-inch refractor was the beginning of solar physics in

America, for it was here that the spectroheliograph originated. Later, when Dr. Hale was chosen director of the Yerkes Observatory of the University of Chicago, he presented the Kenwood instrument to this observatory. In addition, the equipment includes among other instruments a 24-inch reflector and a 40-inch refracting telescope, to this day the largest refractor ever built.

American development in astronomical instruments has kept pace with American leadership in the science of astronomy. Our institutions have trained and developed young men fully competent to carry on. Dr. Hale's successor as director of the Yerkes Observatory was the young astronomer, Dr. Edwin B. Frost, who for over twenty-five years led and inspired the work of this great institution.

Mr. Burnham came to Yerkes in 1897. His contributions to the literature of double star astronomy have been outstanding and his great work—"A General Catalogue of Double Stars within 121° of the North Pole" was published by the Carnegie Institution. He can justly be called the father of double star astronomy in this country, where for so many years he was essentially the only authority on the subject.

Professor Edward E. Barnard also came to the Yerkes Observatory from the Lick and continued his photographic investigation of the Milky Way and comets with the Bruce photographic telescope, built especially for him. Burnham and Barnard have been called the greatest observers of their generation.

The work of Professor Keeler at Lick began a new era in the use of reflecting telescopes in our country. At present we have among the leading reflectors the 60-inch at Mount Wilson, the 69-inch at Ohio Wesleyan, the 72-inch at Victoria, the 100-inch at Mount Wilson and for the future, the proposed 200-inch.

No adequate description of large telescopes and their work could be given without mentioning two other observatories on the Pacific Coast.

The Dominion Astrophysical Observatory at Victoria, under the able directorship of Dr. J. S. Plaskett, has added much to astronomical science by its unabated zeal in making precise measurements of radial velocities. This knowledge of

stellar movements established the fact that the motion of our own sun, relative to the center of our galaxy, is 180 miles per second, which means that it will take something like 250,000,000 years for our own sun, with its neighboring stars, to complete its journey about the center of our galaxy.

Among our great men we have some dreamers and some great builders, but in Dr. George E. Hale we have a great dreamer and a great builder. He dreamed of an observatory on top of Mount Wilson and he built the most magnificent institution of its kind in the world. To tell of the work of the 100-inch and of the 60-inch and the many other unusual telescopes there, is to recount a story which includes all branches of astronomy. He and his distinguished staff, which includes Dr. Walter S. Adams, the present director, Dr. Charles E. St. John, Dr. J. A. Anderson and many others, began with the studies of our sun and now are able to tell us not only many new things about the sun and the stars, but are giving us a much clearer conception of the structure and extent of the universe. It is interesting to note that on the other side of the continent the young and able Dr. Harlow Shapley at Harvard College Observatory has verified and extended this work of the Mount Wilson astronomers.

Man is never satisfied in his quest for knowledge. The 100-inch telescope has given us an insight into space nearly three times greater than had previously been known. The quest now turns to the individual stars in far distant galaxies. For this and other purposes, a larger reflecting telescope is in the process of development, the 200-inch. This will command a volume of space eight times that of the 100-inch and will literally "split apart" some of the celestial objects which we now see as mere entities. In the preparation of such an instrument the difficulties to be overcome are tremendous and yet, it is only with such problems and their solution that the arts keep pace with the vision of mankind. In the 200-inch telescope we are to witness the building of a scientific monument for which our present age will be remembered for generations to come.

In these days the astronomers throughout the country and in some parts of Europe are planning to observe the total eclipse of the sun, which takes place in New England on the

31st of August. This great phenomenon of nature is always of intense interest, not only to the astronomers, but to everyone. If the sun had been a little larger or a little nearer the earth, the moon a little smaller or a little farther from the earth, there would be no total eclipse in New England for the astronomers to observe. May we not feel, however, that the Creator of all things so fashioned the diameters of these heavenly bodies and so directed the movements of the moon and the earth, that men of science might have these special opportunities, occurring from time to time in different parts of the world, for studying the surface of the sun and its eruptions, often extending thousands of miles, and for the study of the corona and the chromosphere; all this that we might learn more of that wonderful heavenly body, the source of light and heat, so vital for the prolongation of life.

As the astronomer reaches out and out into the galaxies of the heavens, and the physicist and geologist delve deeper and deeper into the mysteries of the earth, the words of the psalmist come to us with increasing significance, "The Heavens declare the glory of God, and the firmament showeth His handiwork."

Supercooled Rings of Lead.—(*Chemistry and Industry*, 51, 568.) To the mechanical engineer, perpetual motion is a delusion and a snare; to the physicist interested in subatomic phenomena it is no rarity—witness the measured disintegration of radioactive elements. A remarkable illustration of perpetual motion (almost that, anyway) was presented to the Royal Institution at a recent meeting and the auspicious occasion is described in a vein somewhat facetious by a person signing himself H. E. A. and recognized as one of the constituents in a well-knowned trinity of English chemists.

To fully appreciate the phenomenon described one should have some idea regarding the significance of absolute temperature or ° Kelvin as it is most appropriately termed. 0° K. is known as absolute zero and corresponds very closely to 459.6° F. below zero. It is theoretically impossible to secure a lower temperature than this and in practice the point has been approached to within one degree or even less. In the course of events experimenters have found that many substances cooled to within a few degrees of absolute zero become superconductors for an electric current. In fact some metals appear to become perfect conductors, offering no resistance to the current which, once induced in a ring or coil of the metal, must continue to flow under the influence of its own inertia. The method of demonstrating this fact to the Royal Institution was indeed novel and applause evoking. On the morning of the eventful day, in a world-famous cryogenic laboratory at Leyden, Holland, a lead ring about 1 in. in diameter and ⅛ in. cross-section was placed in a Dewar flask, the innermost of a nest of three. The ring was then covered with 12 liters of liquid helium while the two outer flasks were filled with liquid air. When the lead had attained the very low temperature of liquid helium, a current of 200 amperes was induced in the ring and thus the electronic merry-go-round was established. The set of flasks was then carefully transported to England by aeroplane so it might arrive on time at the meeting. To prove that the current was still flowing in the ring, the Dewar containers were brought near a magnetometer which showed beyond a doubt the electrons had not yet recovered from the start given them over in the Leyden laboratory.

C.

ELECTRIC DISCHARGES IN GASES AT LOW PRESSURES.*

BY

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ABSTRACT.

An analysis of the behavior of electrons and positive ions, when present in relatively large numbers in a gas at low pressures, shows that the fields set up by their motions account for many of the fundamental phenomena of gaseous discharges. The potential distribution arising from current carried by particles of one sign is discussed. When the current carriers are positive ions two cases are analyzed, i.e., the case where the ions all originate at an emitter, and the case where they are generated uniformly throughout the space. In the latter case, when the ions are generated in large numbers, a potential maximum develops in which low speed electrons are trapped. This results in the development of a relatively field-free region, called a *plasma*, which has very different properties from the regions of strong field, called *sheaths*, which cover the electrodes and walls.

The motions of electrons in a plasma are described as a thermal agitation corresponding to a temperature T_e. By virtue of these motions electrons can travel against a small retarding field, the magnitude of which is given by the Boltzmann Equation. These motions cause electrons to travel outward from the center of a plasma until the difference in electron concentration between the center and the edge gives rise to a potential difference of approximately a fraction of a volt, which potential difference accelerates positive ions toward the walls. The motions of positive ions in a plasma can be described roughly as corresponding to a temperature $T_p = T_e/2$. In a mercury arc the positive ion current density I_p is found to be 1/411th of the electron current density I_e, which agrees well with theory.

* This paper has been presented as a report to the International Electrical Congress, Paris, 1932, and is published (in French) as Report No. 7, Section 1.

The properties of sheaths are discussed, and a method is given for calculating the potential drop in the sheath covering the glass wall of a discharge tube. By means of the positive ion sheaths and electron sheaths which cover a collector of variable potential, placed in the path of a discharge, it is possible to measure T_e, I_p, I_e, and the electron concentration n_e.

A theory of the positive column is given, whereby the properties of the column may be determined from the following equations: (1) Plasma balance equation; (2) Ion current equation; (3) Ion generation equation; (4) Mobility equation; and (5) Energy balance equation. Certain experimentally observed properties of the positive column are explained on the basis of a theory that the ratio of the drift current to the random current has a definite value under any given set of conditions, this ratio being uniform along the length of an arc.

When a difference of potential is applied to two electrodes in a gas, and a current flows through the gas between these electrodes, the distribution of potential in the space assumes a wide variety of forms. Some of these are in striking contrast to the distribution obtained with metal conductors. For example, there are many types of discharge in which most of the potential drop takes place within a short distance from the cathode, the rest of the space having practically the potential of the anode. Moreover, it is common to have potential maxima and minima in the space between the electrodes; and it often happens that one of these maxima in space has a potential higher than that of the anode, or a minimum has a potential lower than that of the cathode. These seemingly anomalous phenomena have been shown, in recent years, to represent the normal working of the fundamental electrical properties of gases, which will be the subject of this paper.

Case Where Current is Carried by Particles of One Sign. The potential gradients at any point in space are governed by Poisson's equation,

$$V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 4\pi e(n_e - n_p), \qquad (1)$$

where e is the elementary charge, and n_e and n_p are the concentrations of electrons and of univalent positive ions respectively. Negative ions and ions of multiple charge are normally present in such small numbers that their effects may be neglected. If the current is carried by particles of one sign only (unipolar discharge), Poisson's equation may be solved for cases in which, through symmetry requirements, one of the three independent variables can be eliminated.

A common example of a unipolar discharge is the pure electron discharge in high vacuum. Consider [1, 2] the passage of electrons from a heated plane cathode at zero potential to a parallel plane anode at potential V_a. If the initial velocities of the electrons leaving the cathode are neglected, it follows that at any point at potential V

$$\tfrac{1}{2}m_e v^2 = Ve \tag{2}$$

and

$$n_e e = I_e/v, \tag{3}$$

where I_e is the electron current density, e and m_e the charge and mass, respectively, of the electron, and v the velocity of the electron.

If we replace V, e, n_e and I_e by $-V$, $-e$, n_p and I_p, these equations are obviously applicable to unipolar currents carried by positive ions. In unipolar discharges we shall speak of the two electrodes as emitter and collector.

The solution of Poisson's equation for parallel plane electrodes is

$$I = (2e/m)^{1/2} V^{3/2}/(9\pi x^2) \tag{4}$$

or, substituting $e/m = 5.279 \times 10^{17}$ e.s.u. and expressing V in volts,

$$I = 5.462 \times 10^{-8} M^{-1/2} V^{3/2} x^{-2} \text{ amps. cm.}^{-2}, \tag{5}$$

where I is the current density of electrons or of singly-charged positive ions, M is the "molecular weight" of the carriers of current (oxygen = 16), and x is the distance in cm. from the emitter to the collector. For electron currents

[1] I. Langmuir, *Phys. Rev.*, **2**, 450, 1913.

[2] I. Langmuir and K. T. Compton, *Rev. of Modern Phys.*, **3**, 191–257, 1931. See p. 237 et seq.

$M = 5.479 \times 10^{-4}$ so that

$$I = 2.334 \times 10^{-6} V^{3/2} x^{-2} \text{ amps. cm.}^{-2}. \quad (6)$$

Let us consider the case of current flowing between parallel plane electrodes, and see in what manner the potential in the space between the electrodes is determined by the current passing between them. Figure 1 represents the distribution of potential when electrons flow from a plane emitter at $x = 0$ to a parallel plane collector at $x = a$ and potential V_a. Substituting $V = V_a$, $x = a$, in Eq. (6), we obtain a value for the maximum current that can flow from one electrode to the other. When the current reaches this limiting value it is prevented from rising to higher values by the space charge between the electrodes.

It often happens, however, that the actual current is far less than the maximum given by Eq. (6), for the current may be limited by the rate at which electrons leave the emitter (saturation current). In this case the space charge may be negligible, and the potential distribution may be represented by the straight line 1 in Fig. 1. When en_e is large enough to be important, the potential distribution given by $d^2V/dx^2 = 4\pi en_e$ has a positive curvature. A curve of this type is illustrated by Curve 2, which represents one of a series of curves which could be drawn, the series showing increasing curvature with increasing values of n_e. The limiting current given by Eq. (6) is the current which flows when n_e has increased until the corresponding curvature makes $dV/dx = 0$ at $x = 0$. In other words, there is zero electric field at the surface of the emitter. Curve 2 gives the potential distribution for this particular case.

If the electrons are emitted with initial velocities, there may be a potential minimum M at $x = x_M$, as shown in Curve 3. Under these conditions only those electrons can pass to the collector which are emitted with sufficient normal velocity components to enable them to travel against a retarding field from $x = 0$ to x_M. A complete analysis of this case has been given in a previous paper.[3] If the initial velocities of the electrons have a Maxwellian distribution

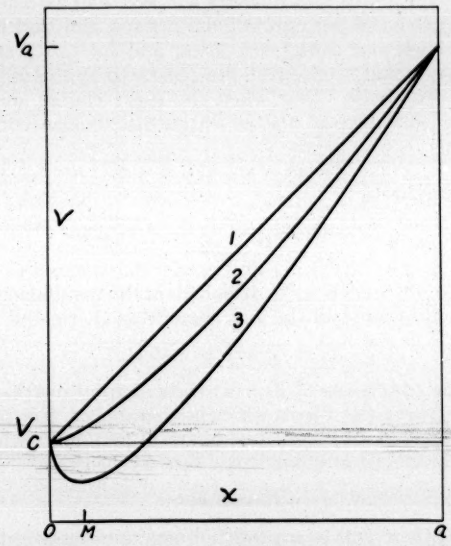
[3] I. Langmuir, *Phys. Rev.*, **21**, 419, 1923. See also Ref. 2, p. 239 et seq.

corresponding to a temperature T, we obtain in place of Eq. (5)

$$I = 5.462 \times 10^{-8} M^{-1/2} V^{3/2} x^{-2} [1 + 0.0247(T/V)^{1/2}] \text{ amp. cm.}^{-2}. \quad (7)$$

Here V is in volts and V and x are both measured from the point M in Fig. 1, taken as origin.

FIG. 1.



Potential distributions in unipolar discharges between parallel plane electrodes.

Corresponding space charge equations for the maximum unipolar currents between electrodes in the form of coaxial cylinders or concentric spheres have been derived.[4]

Positive Ion Currents. All these equations are applicable

[4] I. Langmuir and K. B. Blodgett, *Phys. Rev.*, **22**, 347, 1923, and **23**, 49, 1924. See particularly Ref. 2, p. 245 et seq., for curves of the functions α and β involved in these calculations.

to unipolar currents carried by positive ions originating at a plane emitter.

The more general cases of positive ion currents, however, are those in which positive ions are generated throughout the space between the electrodes. Let us consider, for the sake of simplicity, the case where ions are produced uniformly throughout the space between a plane electrode A and a parallel plane electrode C which has a potential V_c with respect to A and is at a distance a. We shall assume that S ions are produced per unit volume per sec. and that they are produced without initial velocities, and for the present we shall assume that no electrons are generated by this ionization. It has been shown [5] that when the space charge and corresponding curvature of the potential distribution curves are such that

$$dV/dx = 0 \quad \text{at} \quad x = 0,$$

it follows that

$$I_c = (2e/m_p)^{1/2}(-V_c)^{3/2}/(\pi^2 a^2), \tag{8}$$

where I_c is the current per unit area which reaches C. Comparing Eq. (8) with Eq. (5), which gives the maximum current I that could flow if all the ions came from A, we find that

$$I_c = (9/\pi)I = 2.865I. \tag{9}$$

Under the conditions of Eq. (8) the potential distribution is given by Curve 1 of Fig. 2, which is a parabola. The relationships expressed by these equations obtain only when the ions are produced at a particular rate S_1 such that

$$I_c = S_1 ea. \tag{10}$$

If $S > S_1$ there will be a potential maximum between A and C and Eq. (8) can then be applied separately to the two branches of the curve on opposite sides of the maximum. The potential distribution curve is thus still a parabola but the origin is no longer at A. The curves marked 2, 3, 5 and 10 in Fig. 2 have been calculated for values of S equal respectively to 2, 3, 5 and 10 times S_1.

We have, then, the result that when ions are generated at a uniform rate throughout the region between two parallel

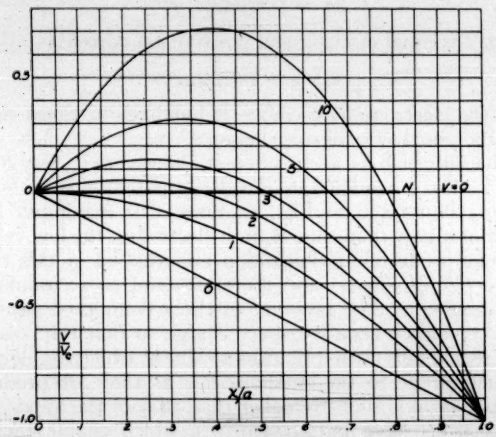
[5] I. Langmuir, *Phys. Rev.*, 33, 954, 1929. See p. 961.

planes and there is no appreciable accumulation of electrons, the potential distribution is parabolic, that is, the potential is governed by the equation $V = Br^2$ where r is measured from the plane at which the potential is maximum. The ion concentration n_p is then uniform throughout the volume and its value is governed by the equation,

$$n_p = 0.0112 M^{1/3} S^{2/3} \text{ ions cm.}^{-3}, \qquad (11)$$

if S is expressed in ions cm.$^{-3}$ sec.$^{-1}$.

FIG. 2.



Potential distributions between parallel plane electrodes when ions are generated uniformly between them.

If the region in which ionization occurs is bounded by a cylindrical surface instead of parallel planes, or if it is bounded by a spherical surface, a parabolic distribution exists also, that is, $V = Br^2$ where r is now the distance from the axis of the cylinder or the center of the sphere. In these cases, similarly, the ion concentration is uniform throughout the volume so that Eq. (11) is applicable except that the value of the coefficient is 0.0105 for the cylindrical case and 0.0102 for the spherical case.

Effect of Electrons Generated by Ionization. If the positive ions are produced by the ionization of the gas, an equal number of electrons are generated simultaneously. If $S < S_1$ there will be no potential maximum between the electrodes so that these electrons flow to the electrode A as fast as they are generated. There is therefore an electron current flowing to A which is equal to the positive ion current flowing in the opposite direction to C, but the electron current has no appreciable effect on the space charge. This follows from the result of combining Eqs. (2) and (3) by which we find that

$$en = I[m/(2Ve)]^{1/2}, \tag{12}$$

so that for equal electron and positive ion currents

$$n_e/n_p = (m_e/m_p)^{1/2}. \tag{13}$$

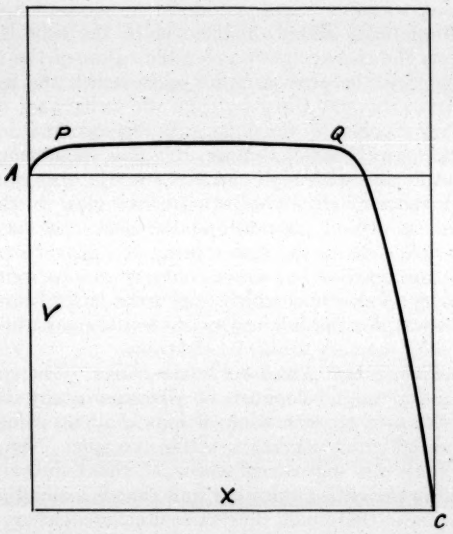
Thus the electron space charge is hundreds of times smaller than the positive ion space charge.

The situation is very different, however, if $S > S_1$, for there is then a tendency to develop a potential maximum of the sort illustrated in Fig. 2. Since this maximum has a potential higher than that of both electrodes, the low velocity electrons produced by ionization are trapped in this region (above ON in Fig. 2) and therefore tend to accumulate in large numbers. The presence of the accumulated electrons, however, adds a negative space charge so that the potential of the region falls until it reaches a value at which the electrons can just escape to the anode as fast as they are produced. This potential is slightly higher than that of the anode since the electrons have initial velocities which enable them to travel against a small retarding field.

Figure 3 shows the type of potential distribution which results from the trapping of electrons according to the process just described. Positive ions flow in an accelerating field from P to A and from Q to C; electrons flow against a retarding field from P to A only. There are practically no electrons in the region between Q and C, as the strong retarding field bars them from entering this region. The space between P and Q is brought to nearly uniform potential by the electrons trapped in this space (assuming for the present that no electrons disappear from this region except those which

travel to A). The reason for this levelling of potential is clear when we consider that the electrons, because of their high mobility, accumulate instantly in a potential maximum and thus lower its potential, whereas they travel out from a minimum and thus raise its potential. Since the region between P and Q is therefore a region of very small electric field, the number of electrons per unit volume in this space

FIG. 3.



Potential distribution arising from the trapping of electrons in a region having a potential maximum.

must be nearly the same as the number of positive ions, in other words, the electrons neutralize the positive ion space charge and we have $n_e = n_p$.

We see now that there are two distinct types of regions in a space bounded by electrodes when the current between the electrodes is carried by both positive ions and electrons. The regions of strong field due to space charge which cover

the electrodes will be referred to as the *sheaths*. PA represents the potential drop in an anode sheath, and QC in a cathode sheath. The relatively field-free region between the sheaths will be called the *plasma*. These regions must be described separately as they have very different properties.

Many of the phenomena of gaseous discharges which are commonly visible to the eye are due to the different properties of these two regions. For example, when a current of a few milliamperes from a hot cathode is flowing in a glass tube containing mercury vapor saturated at room temperature, the voltage being above about 20 volts, the tube is largely filled with the characteristic green-blue glow of the mercury discharge, but the glow does not quite reach the walls. A dark space separates the glow from the walls, as if the glow were being repelled by the glass. As the current is increased the dark space becomes thinner, the glow advancing nearly to the wall; and with high currents the eye does not detect the dark space at all. The region of the glow, in this case, represents a typical plasma, and the dark space a typical positive ion sheath, the latter being a region from which electrons are repelled but which contains positive ions. It is the scarcity of electrons which causes the lack of luminosity in the sheath, for the luminosity of the plasma is due to the excitation of mercury atoms by electrons.

Conditions under Which a Plasma Forms. The condition necessary for the development of a plasma in any discharge is that the rate of generation of ions shall be sufficient to produce a potential maximum within the tube. By Eq. (9) we see that this will occur whenever the number of ions produced in the entire space per unit time is a small multiple of the number that could flow as a unipolar discharge if the ions were all generated at the anode. With voltages of the order of 100 volts between electrodes 5 cm. apart, we thus see from Eqs. (9) and (5) that the plasma should first begin to appear when the positive ion currents exceed about 4.5×10^{-7} amp. cm.$^{-2}$ in the case of mercury vapor ($M = 200$), or 3.2×10^{-6} amp. cm.$^{-2}$ with helium ($M = 4$).

At pressures so high that the electron free paths are short compared to the distances between the electrodes, the number of ions (β) produced by each electron emitted from

the cathode (total ionizing power [6]) is independent of pressure. For 100 volt electrons in mercury vapor $\beta = 2.7$ and in helium $\beta = 2.9$. Thus the electron current density at 100 volts needed to produce a plasma in mercury vapor under the assumed conditions is 1.7×10^{-7} amp. cm.$^{-2}$ and in helium 1.1×10^{-6} amp. cm.$^{-2}$. At lower pressures if the electrons pass directly from anode to cathode, the ionizing power is proportional to the pressure and to the distance between the electrodes. At a pressure of 0.001 mm. at 28° C. and with electrons of 100 volts, the ionizing power * per electron in mercury vapor is 0.0213 cm.$^{-1}$ and in helium 0.0016 cm.$^{-1}$, and therefore with an electron current density of 1 ma. cm.$^{-2}$ we can calculate that the gas pressure at which a plasma should first appear is about 4×10^{-6} mm. for mercury vapor and 4×10^{-4} mm. for helium.

These calculations serve to illustrate the fundamental factors which determine the occurrence of phenomena that are characteristic of gaseous discharges, as contrasted with the pure electron discharges that occur in high vacuum. Actually because of losses of ions to the walls of the tube and other secondary factors, the currents needed to produce a well defined plasma are somewhat greater than those calculated above.

Properties of Electron Currents in a Plasma. The most fundamental characteristic of a plasma is that it is a region in which electrons accumulate or are trapped until their concentration is approximately equal to that of the ions so that $n_e = n_p$. In gases at low pressures of a few millimeters or less, the recombination of the ions and electrons has been found to take place at a practically negligible rate in typical plasmas. The main reason for this is that the electrons move in orbits among the ions and only rarely collide with them; even in the case of a collision the probability of a recombination appears to be rather low.

In the ionization process in which a high speed electron collides with a neutral gas molecule, the momentum of the electron is so small that it cannot give any appreciable

[6] K. T. Compton and I. Langmuir, *Rev. of Modern Phys.*, **2**, 123–242, 1930. See Table II, p. 127.

* See Reference 6, Table I, p. 127.

kinetic energy to the ion which is formed, so that the kinetic energies of the ions when first formed will be the same as those of the neutral gas molecules. The ionization, however, produces a new electron so that there are two electrons in place of the original one. The surplus energy of the original electron, after subtracting that necessary for ionization, is divided between the two electrons in variable ratios. In general, therefore, the electrons in a plasma acquire very considerable energies when they are first generated by ionization. A few of the electrons with the highest kinetic energies may thus be able to escape through the anode sheath, whereas those that have smaller kinetic energies are unable to escape and continue to move within the plasma, being continually reflected from the sheaths which bound it. The interactions between these electrons and the elastic collisions which they may make with gas atoms thus tend to produce a random motion among the electrons. The distribution of velocities tends toward a typical Maxwellian distribution such as that which exists among the molecules of a gas at a definite temperature. In fact, the motions of the electrons within the plasma may be well described as a thermal agitation corresponding to a temperature T_e. Experiments have shown that in most gaseous discharges, especially those at very low pressures, this Maxwellian distribution of the velocities of the electrons is brought about far more rapidly than is to be expected from any known mechanism.[7, 8] The experiments indicate that this phenomenon is intimately connected with the presence of very high frequency oscillations that occur within the plasma, these having frequencies corresponding to

$$\nu = e(n/\pi m_e)^{1/2} = 8980 n_e^{1/2} \text{ sec.}^{-1}. \qquad (14)$$

The electron temperatures determined by a method which will be described presently have been found to range from about 5000° K. up to temperatures in some cases as high as 80,000° K. The average energies of these electrons, therefore, range from about 1 up to 10 electron volts.

With the electrons thus moving in random directions, there is a definite *random current density* I_e of electrons

[7] I. Langmuir, *Proc. Nat. Acad. Sci.*, 14, 627, 1928.

[8] L. Tonks and I. Langmuir, *Phys. Rev.*, 33, 195, 1929; see Ref. 6, p. 239.

passing per second per unit area across any imaginary plane within the plasma. From equations of the kinetic theory it is thus found that this current density is given by

$$I_e = en_e(kT_e/2\pi m)^{1/2} = 2.48 \times 10^{-14} n_e T_e^{1/2} \text{ amps. cm.}^{-2}. \quad (15)$$

When gas molecules in thermal equilibrium are exposed to a steady field of force, their concentration becomes different in places of different potential energy. In such cases the distribution is determined by the Boltzmann equation. For the case of electron distributions, the Boltzmann equation takes the form,

$$n = n_0 \epsilon^{Ve/kT}, \quad (16)$$

where n is the concentration of electrons at any place of potential V, and n_0 is the concentration at a point where the potential is zero. For numerical calculations in this equation we may put $e/k = 11{,}606$ degrees per volt. We thus see that if there are differences of electron concentrations in different parts of the plasma, there will be corresponding potential differences, or conversely, differences of potential necessarily involve differences of concentration if our assumption of thermal equilibrium is valid.

In the case of an arc discharge contained in a long tube, the region commonly called the positive column is a typical plasma. When considerable current is flowing, there is normally a small potential gradient throughout the length of the cylindrical plasma. The electrons in the plasma are therefore being accelerated by the field which acts on them, but soon a stationary stage is reached in which the energy losses of the electrons by their collisions with gas molecules just balance the gain in energy produced by the field. With a long uniform positive column, the electron temperatures are then the same throughout the plasma, but the concentration is also uniform in spite of the potential gradient. Thus the Boltzmann equation is not applicable to determine changes in concentration along the length of the arc, but it may well be used to determine variations of concentration over a cross-section.

In general, therefore, we must distinguish between two kinds of current within the plasma, the random currents having a density I_e and the drift currents having a density

I_d, due to any applied electric field. The energy input per unit volume into the plasma is thus the product of I_d by the potential gradient. In most typical discharges the random current density is at least several times greater than the drift current density.

Properties of Positive Ion Currents in a Plasma. If the positive ions had kinetic energies approximately equal to those of the electrons and were also moving in random directions, it would follow that the positive ion current densities I_p would be less than I_e in the ratio of $m_e^{1/2} : m_p^{1/2}$. In the case of mercury vapor, therefore, I_p would be $(1/605)I_e$. Experimentally, by methods to be described later, it is usually found in a mercury arc that $I_p = (1/411)I_e$.

We have seen, however, that the positive ions are generated without initial velocities. It is thus very improbable that the ions should acquire a Maxwellian distribution of velocity.

In any plasma in a steady state, that is, if n_p does not increase with time, it is necessary that the ions shall move out of the regions in which they are generated as fast as they are produced. This will require the presence of electric fields drawing the ions from these regions; these fields can be set up only by the presence of a slight excess of positive charge within the plasma. The fact that the electrons have relatively high energies tends to make them move out of the plasma, leaving behind an excess of positive charge. This positive charge builds up until it causes ions to flow out from the plasma into the surrounding sheaths at a rate equal to that at which they are produced. At such low pressures that the ions move under the influences of these plasma fields without colliding with gas molecules, the motions of the ions are governed by equations similar to equations (2) and (3), except that account must be taken of the fact that different ions originate in different positions.

A complete mathematical theory of the motions of ions under these conditions has been developed by Tonks and Langmuir.[9] The general solution for electrodes of any shape would be extremely complicated. However, a solution can be worked out for the case where the plasma is bounded by two parallel planes or by a cylindrical or a spherical surface.

[9] L. Tonks and I. Langmuir, *Phys. Rev.*, **34**, 876–922, 1929.

Two cases have been considered: at low pressures the ions fall freely from their points of origin to the boundary of the plasma; at high pressures they move according to the laws governing the mobility of ions which continually make collisions with the gas molecules. In the present paper we shall consider only the first of these cases.

Assuming that the rate of generation of ions S at any point is proportional to the concentration of electrons at that point, the characteristics of a plasma may be expressed in terms of a parameter λ which may be defined as the number of ions generated per second by each plasma electron. Tonks and Langmuir have shown that in order that the plasma fields determined by the Boltzmann equation may draw out the ions as fast as they are generated, it is necessary that the following *plasma balance equation* be fulfilled,

$$\lambda = (s_0/a)(2kT_e/m_p)^{1/2}, \tag{17}$$

where a is the radius of the plasma in the case of a cylindrical plasma, or is half the thickness of the plasma when this is bounded by two parallel planes. The factor s_0 is a pure number which has the value 0.7722 for the cylindrical case and 0.4046 for the parallel plane case. Inserting numerical values we thus find that

$$\lambda = (9957/a)(T_e/M)^{1/2} \tag{18}$$

for cylinders, and

$$\lambda = (5217/a)(T_e/M)^{1/2}$$

for parallel planes, where M is the molecular weight of the ion. For mercury vapor in a cylindrical plasma ($M = 200$), this gives

$$\lambda = (703/a)T_e^{1/2}. \tag{19}$$

The plasma balance equation thus requires a definite relationship between λ and T_e. With a mercury arc of one ampere flowing through a long glass tube of 1.6 centimeters radius containing mercury vapor at room temperature, T_e was found to be 29,000 and thus, according to Eq. (19), λ, the number of ions generated per second by each plasma electron, was equal to 75,000.

If the rate of production of ions S, instead of being proportional to the electron concentration n_e, is uniform

throughout the plasma, then the plasma balance equation takes the form:

$$n_0 = (Sa/s_0)(m_p/2kT_e)^{1/2}. \qquad (20)$$

In this case s_0 has the value 0.583 for a cylindrical plasma and 0.380 when the plasma is bounded by parallel planes. In this equation n_0 is the electron concentration at the center of the plasma. In the cylindrical case this equation reduces to

$$n_0 = 1.33 \times 10^{-4} Sa(M/T_e)^{1/2} \text{ ions cm.}^{-3} \qquad (21)$$

According to this theory of the plasma, the velocities of the ions are very small at the center of a cylindrical plasma, and the radial velocities increase gradually toward the cylindrical bounding surface. The positive ions thus do not have a Maxwellian distribution of velocities nor is their distribution in accord with the Boltzmann equation. The energies which the ions receive are derived from the plasma fields which are set up by the motions of the electrons. The average energies of the ions are, however, considerably less than the average energies of the electrons. Experiments in which the ions fell through a perforated collector so arranged that the velocities of the ions could be measured [10] prove that the radial components of the ion velocities were roughly that which they would have if the ions had a temperature about one-half that of the electrons. As an approximation, therefore, at the edge of the plasma, we may consider that the ions have a Maxwellian distribution with $T_p = T_e/2$, but must recognize that the ions are moving outward from the center of the plasma, toward and into the sheath which bounds the plasma, whereas the electrons with a true Maxwellian distribution are moving equally in all directions, being reflected from the negatively charged region in the sheath. Taking these facts into account, it has been shown * that the ratio of the positive ions to the electron current density is approximately given by

$$I_e/I_p = (1/2)(T_e m_p/T_p m_e)^{1/2}. \qquad (22)$$

[10] L. Tonks, H. Mott-Smith, Jr., I. Langmuir, *Phys. Rev.*, **28**, 104, 1926. See pp. 120–123.

* Ref. 5, p. 965. Ref. 9, p. 880.

For mercury vapor this gives

$$I_e/I_p = 429. \tag{23}$$

Experimentally the average value for this ratio was found to be 411 ± 17.

From measurements in which I_e and T_e are determined, the concentration of electrons and ions in the plasma may be calculated according to the equation,

$$n_e = 4.03 \times 10^{13} I_e/T_e^{1/2}, \tag{24}$$

which is the equivalent of Eq. (15).

Plasma Fields. Although the potential of the plasma is not entirely uniform, the drop in potential from the center to the sheath edge is only about $5 \times 10^{-5} T_e$ and is thus usually less than one volt. It is these plasma fields, however, which give to the ions their velocities.

Near the center of a plasma there is a potential maximum, and the potential in the rest of the plasma varies approximately proportionally to the square of the distance from this central point of maximum potential. The electron concentration falls off very slightly as this radial distance increases, in accord with the Boltzmann equation as applied to the plasma fields. The ion concentration, however, is much more nearly uniform and is not affected by the factors involved in the Boltzmann equation. As a result, near the walls of the tube the electron concentration decreases much more rapidly than the ion concentration and there is thus a relatively large positive space charge. This causes a rapid decrease in potential with increasing radial distance, and thus the concentration of electrons decreases practically to zero. The transition from plasma to sheath, although not discontinuous, takes place within a comparatively small distance and for practical purposes we may consider the regions as being distinguished from one another.

Properties of a Positive Ion Sheath. If the glass walls of a tube containing a plasma were at the same potential as the plasma itself, the current relationship given by Eq. (23) shows that the walls would receive electron currents hundreds of times greater than correspond to the positive ions that reach the walls. Actually, in a steady state, the number of

negative and positive charges which reach an insulated wall must be equal. To render these currents equal, the walls must therefore become so highly negatively charged that they force nearly all the electrons back into the plasma. The walls thus become covered with a positive ion sheath. The potential drop in this sheath can be calculated by means of the Boltzmann equation, Eq. (16). Since the electron temperature is uniform throughout the plasma, the current density I which moves against the retarding field in the sheath is proportional to the electron concentration n and thus Eq. (16) may be written,

$$I = I_0 \epsilon^{V_s/kT_e}. \tag{25}$$

In the case of mercury vapor the electron current density I which reaches the wall being equal to I_p is thus about $(1/429)I_0$, where I_0 is the electron current density in the plasma near the sheath edge. The potential drop in the sheath is therefore

$$V_s = -6.06T_e/11600, \tag{26}$$

so that if $T_e = 25000°$, the walls of the tube are about 13 volts negative with respect to the edge of the plasma.

Within the positive ion sheath the conditions are closely similar to those in the typical unipolar discharge. The ions from the plasma reach the sheath edge moving radially outward with energies of usually less than one volt. Within the sheath, however, they are acted on by strong electric fields which accelerate them rapidly toward the walls. It is therefore apparent that the space charge equation, Eq. (5), is applicable to the positive ion currents that flow through these sheaths. If we do not wish to neglect the effect of the initial velocities with which the ions enter the sheath, we may make use of Eq. (7). In this equation T may be put equal to $1/2T_e$; V is the voltage drop through the sheath and I is equal to I_p, the positive ion current density in amps. cm.$^{-2}$ which flows out from the plasma. We can thus calculate the thickness of the sheath by Eq. (5) or (7). The higher the positive ion current density, the thinner the sheath must become.

Use of Collectors in Studying Discharges. By covering a portion of the glass wall which encloses a plasma by a metal

electrode or collector, the rate of arrival of the positive ions at the wall may be readily measured.[11] When this collector is made negative with respect to the plasma, a positive ion current of density I_p flows to the collector and electrons are repelled; and if the negative potential is made sufficiently great, no electrons reach the collector. This occurs when the potential of the collector is greater than -5 to -10 volts with respect to the neighboring plasma. Experiment shows that when all electrons are repelled the current flowing to a plane collector is nearly independent of the applied voltage and thus is a true measure of I_p. For example, in the case of a plane square collector, 1.9 cm. on a side, placed flush with the wall of a tube containing a 2-amp. arc in mercury vapor at 0.025 mm. pressure, the voltage E and current i at the collector were as follows:

E Volts.	i Milliamps.
-80	-2.87
-50	-2.75
-30	-2.64

Even this small variation of current with voltage is accounted for as an effect due to the edges of the collectors. If the voltage is changed, the sheath over the collector changes in thickness, whereas that over the surrounding glass walls does not change. The sheath boundary is therefore a curved surface near the edges of the collector. Equations have been derived * by which corrections for this effect may be calculated for square and disk shaped collectors. The effect may, however, be eliminated by surrounding the collector by a guard-ring which is maintained at the same potential, the current density, however, being measured only by the inner collector. When this is done in mercury vapor, it is found that these positive ion currents remain constant up to negative voltages of 1200 volts.

If the potential of a collector is raised gradually (i.e., the negative potential is lowered) until it is no longer able to repel all of the electrons from the plasma, the collector

[11] I. Langmuir and H. M. Mott-Smith, Jr., *G. E. Rev.*, **27**, 449, 538, 616, 762 (1924).

* See Ref. 11, pp. 540–543.

current no longer remains constant, but decreases in magnitude from the value corresponding to I_p because the collector is now receiving both positive ions and electrons. As the potential is raised still further, the current passes through zero and increases with the opposite sign. These increments of electron current afford a measure of the electron current density I_e which is able to move against a negative potential applied to the collector. From Eq. (25) it is seen that the logarithms of these values of I_e should vary linearly with the voltage V and that the slope of the line obtained by plotting lnI_e against V gives $e/kT_e = 11{,}606/T_e$.

Experiments made under a wide variety of conditions have yielded semi-logarithmic plots which were straight over a range covering a 1000-fold increase in I_e. It has been established by these plots that in nearly all cases the electrons in a plasma have a Maxwellian distribution of velocities; moreover that this distribution is maintained in spite of the fact that the walls constantly remove the faster electrons, so that the equilibrium when disturbed must be reëstablished with surprising rapidity.[12] In a mercury arc the electron temperatures T_e given by the slope of these semi-logarithmic plots decrease markedly as the mercury vapor pressure is raised, but are nearly independent of the arc current. The average values are as follows:

Pressure.	T_e.
1.05 baryes	25,000 deg. K.
3.7 baryes	18,500 deg. K.
33.0 baryes	8,900 deg. K.

Properties of an Electron Sheath. If the collector potential is raised to a point where it becomes equal to that of the plasma, the positive ion sheath disappears and the electron currents that are received by the collector are on the average about 400 times greater (for mercury vapor) than the steady positive ion currents I_p obtained at large negative voltages. Up to this voltage the semi-logarithmic plots of I_e are straight. If the collector voltage is raised above this point, however, I_e tends to remain constant, for the collector is receiving all the electrons which are flowing toward it in the plasma.

[12] I. Langmuir, *Phys. Rev.*, **26**, 585, 1925. See pp. 586–592. For a detailed discussion see Ref. 9.

The effect of raising the voltage above this point is merely to push back the positive ions in the plasma and cause an electron sheath to develop over the collector in which the flow of current is unipolar and the thickness of the sheath can be calculated by the space charge equation (5) or (7). The voltages cannot be raised very far, however, without accelerating the electrons in this electron sheath to such an extent that additional ionization occurs and then the electron sheath breaks down and much larger currents can flow to the collector.

It is, however, a characteristic feature of these volt-ampere characteristics of a collector that there is a relatively sharp kink in the plot of lnI_e against V when the collector is at the same potential as the plasma. The position of the kink affords an accurate determination of the space potential.

Theory of the Positive Column at Low Pressures. Let us apply these concepts to the consideration of the typical properties of a low pressure arc such as that which occurs when currents of 0.1 ampere or more are passed through cylindrical tubes containing mercury or neon at low pressures. Any particular arc is characterized by a large number of variables. We may choose some of these as independent and take the others as dependent variables. For example, if we choose a certain gas at a definite pressure and temperature in a tube of given diameter and have an arc carrying a given current, we may regard these variables as the independent variables. Fixing their values, the characteristics of the arc are uniquely defined. We may wish to calculate the following five dependent variables: viz., electron concentration n_0 at the axis of the tube; electron temperature T_e; positive ion current density I_p reaching the wall; rate of production λ of ions per electron per second; and potential gradient dV/dx along the axis of the tube. To determine these five unknown quantities we need five equations. From the theories outlined above, it can be seen that at least formally we can give[9] five equations necessary for the determination of these unknowns. The five equations are as follows:

1. *Plasma Balance Equation*, Eq. (19) or Eq. (22).

2. *Ion Current Equation.* The total ion current reaching the walls is equal to the total number of ions produced

within the plasma since recombination is negligible. This equation can be expressed by

$$I_p = h_0 e a n_0 \lambda, \tag{30}$$

where h_0 has the numerical value 0.350 for a cylindrical plasma when the rate of ion generation at any point is proportional to the electron concentration.

3. *Ion Generation Equation.* Killian,[13] and Tonks and Langmuir [9] have shown that the rate of generation of ions λ in a mercury arc can be accounted for as the normal result of the ionization from the high speed group of electrons present in the Maxwellian distribution corresponding to the temperature T_e. Equations for calculating the ion generation have been derived in this way.

4. *Mobility Equation.* Langevin's mobility equation gives an expression for the average drift velocity of the electrons in terms of the pressure of the gas, the longitudinal potential gradient and the electron temperature. In this way an equation is obtained which contains these quantities together with the concentration of electrons n_0.

5. *Energy Balance Equation.* The total energy put into the arc must be equal to the total output. About one-third of the energy in the case of a low pressure mercury arc is required to supply the positive ions and electrons which recombine on the walls. Probably most of the rest of the energy escapes from the arc in the form of radiation, some of which passes through the glass, while much of the ultraviolet light is intercepted by the glass. At present the factors required for this energy balance equation are only imperfectly known.

With these five equations all the variables of the arc can theoretically be fixed and thus the main features of these arcs are understandable from our present knowledge of the phenomena involved.

Ratio of Drift to Random Current I_d/I_e. From the foregoing theory of the low pressure arc, the ratio of the drift current to the random current has a definite value under any given set of conditions, this ratio being uniform along the length of the arc.

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[13] T. J. Killian, *Phys. Rev.*, **35**, 1238, 1930.

If we have an arc in a tube which varies in cross-section along its length, the drift current density I_a must vary in inverse proportion to the cross-section of the tube since the total drift current must remain constant. Similar changes must occur also in the random current I_e. At any point where there is a sudden change in diameter of the tube, there will therefore be differences in the values of n_e between adjacent points which will require, in accordance with the Boltzmann equation, corresponding differences of potential. If, at the cathode end of a constriction of the tube, the random current density of electrons moving towards the constricted area is not sufficient to carry the drift current into this region, an increased potential gradient will occur near the constriction, the electrons being accelerated to a velocity which causes them to produce new ions. There will thus be formed a double layer or double sheath across the arc in which there is a potential drop corresponding roughly to the ionizing potential. This causes a luminous appearance in the tube which resembles that at the head of the positive column of a typical low pressure gaseous discharge.

At the anode end of the constriction the electron concentration in the narrow part is several times greater than that in the larger part next to it. In accordance with the Boltzmann equation, therefore, a retarding field of several volts will be set up, corresponding to this difference of concentration. Because of the surplus of high speed electrons in this region, more than are needed to preserve the normal ratio I_d/I_e, there will be a tendency for the electron temperatures to decrease in this region and less ionization will occur so that there will be less luminosity. This region therefore will appear as a dark space. It is believed that this is entirely analogous to the Faraday dark space in ordinary discharges. In fact, dark spaces of this kind can be easily produced artificially at any point by allowing electrons to be emitted from a negatively charged hot filament introduced into the plasma. The Faraday dark space, therefore, may be looked upon as a region in which the ratio I_d/I_e has less than the normal value needed to maintain a positive column.

The cathode, or Crookes, dark space in a typical low pressure discharge is merely a positive ion sheath in which

the electrons from the plasma are repelled from the negatively charged cathode. The space charge equations apply, however, only roughly to this cathode dark space because the ions do not all originate at the edge of the dark space, but many are produced within the sheath itself by the high speed electrons coming from the cathode. The fact that an appreciable part of the current is carried by these electrons also prevents the accurate application of the space charge equations.

The cathode glow marks a region where the electron concentration is very high and the electron temperature T_e is high because of the presence of many high speed electrons arriving from the cathode. Because of this excess ionization the ratio $I_d : I_e$ is abnormally small and therefore the cathode glow is followed by the Faraday dark space. When this ratio has fallen just below its normal value, there is no longer a sufficient production of ions to satisfy the plasma balance equation. This results in the production of a field at the head of the positive column which accelerates electrons and produces the required number of ions. If more than enough ions are produced than are required to satisfy these equations, a striated discharge results and we have a succession of Faraday dark spaces alternating with heads of positive columns. If, however, the conditions are such that at the head of the positive column the number of ions produced as a result of the double sheath conforms more nearly to the requirements of the equations, then a uniform positive column results.

If the anode is of large size so that its area multiplied by I_e is greater than the drift current, there will usually be a slight negative anode drop of a volt or so. If the anode, however, is of very small size so that the random current striking it is not sufficient to carry the current required by the external circuit, then we have conditions similar to those occurring at the beginning of a striation, viz., a double sheath must form and a second plasma will form within the first. This will produce an anode glow in the form of a more or less spherical region of glow attached to the anode. These concepts involving the ratio $I_d : I_e$ thus help to explain, at least qualitatively, the most important characteristics of typical low pressure discharges.

ELEMENTARY THEORY OF THE GYROSCOPE.

BY

PETER L. TEA, E.E., M.A.

The object of this paper is to present the fundamental properties of the gyroscope in an elementary manner, suitable for second year students of Physics.

The motion of each particle of the gyro disc will be followed, and its contribution to the overall effect studied.

We will limit the study to two sets of conditions, (*A*) intersecting and mutually perpendicular axes of precession, of torque, and of the axle of the rotating disc, considering only small variations from the mutually perpendicular position, (*B*) The axle of the gyro does not move far from the precession axis. The point of intersection of the axes and axle is fixed in space.

Seven cases will be considered: (I) Addition of Uniform Displacements; of uniform displacements and the displacement due to a constant force; under (*A*) (II) Uniform precession about an axis fixed in space, (III) Sudden removal of the torque from a free gyro, or the motion produced by an impulse, (IV) Forced uniform precession about a fixed axis in space, on a free gyro, (V) Nutation produced by suddenly applying a torque to a free gyro, (VI) Torque gradually applied; Under (*B*) (VII) Gyro Pendulum; Top.

It is hoped that our method of presenting the above studies will serve to impart a more intimate knowledge of the gyroscopic phenomena to the undergraduate student, lead to quantitative laboratory work, and form the basis for a more general, advanced study, using vectors to represent each angular moment of momentum, and their interactions followed.

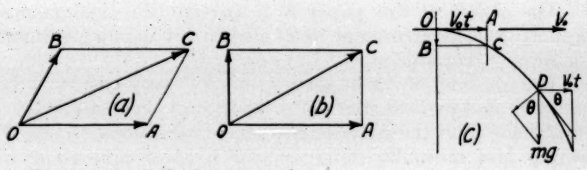
I. MOTION OF A PARTICLE; ADDITION OF UNIFORM DISPLACEMENTS; ADDITION OF A UNIFORM DISPLACEMENT AND THE DISPLACEMENT DUE TO A CONSTANT FORCE; CONSTRAINTS.

In Fig. 1, (*a*) and (*b*), uniform displacements of a particle, one along *OA*, the other along *OB*, are added. At any instant

the particle will be found along the diagonal OC, in the plane of OA and OB.

In Fig. 1, (c), a displacement at constant velocity V_0, say horizontal, in the direction OA, is added to the vertical displacement produced by gravity, at right angles to V_0.

FIG. 1.



The vertical displacement is

$$OB = \frac{1}{2} g t^2. \tag{1}$$

This displacement is constant in direction, but varies as the square of the time t. The particle will be found at the end of the diagonal OC, but OC constantly changes its direction. Equation (1) gives the vertical displacement for any value of t, measured under tangent. It can also give the displacement to the trajectory measured at right angles to any tangent, provided that instead of g we use the acceleration at right angles to the tangent. But now the displacement can be computed for a small value of t only, since the acceleration component varies.

In Fig. 2, (a), if a particle at constant velocity V enters the cup O, held by a wire with a loop at the other end, about a nail fixed to a board, the particle will describe a circle, of radius R, the plane of the circle being determined by V and point N. There are two displacements, one Vt, without constraint, and the other $OB = AC$, at right angles to V, if t is limited to a small value, constraining the particle to follow the arc OC.

The value of AC in terms of V and t is:

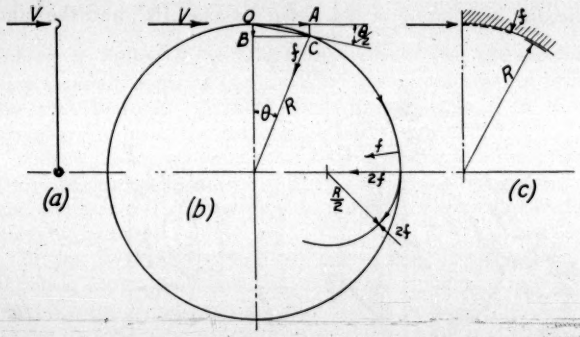
$$AC = OB = R\theta \frac{\theta}{2} = \frac{v^2 t^2}{2R}. \tag{2}$$

This displacement corresponds to one due to a constant force f, acting on the particle of mass m,

$$\frac{1}{2}\frac{f}{m}t^2 = \frac{v^2t^2}{2R}$$
$$f = \frac{mv^2}{R}. \qquad (3)$$

At C the same conditions exist as at O. The force f constraining the particle to follow the circle, is therefore constant, directed towards the center, and the velocity on the circumference is constant and numerically equal to V. The radial acceleration v^2/R, is towards the center, constantly changes its direction at a uniform rate, and starts immediately at O, as does the force. The velocity towards the center v^2t/R, never gets a chance to develop, since the two displacements above mentioned, maintain R constant.

FIG. 2.



The force f does no work, since there is no motion along the radius, and hence the circular motion would continue indefinitely if it were not for friction which slows up the motion, and f grows less with it.

In Fig. 2, (b) if a cord is used instead of the wire, and it catches on a nail reducing the radius to one half, the force f,

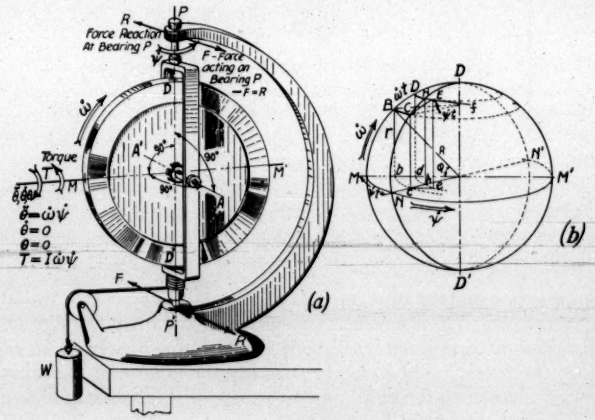
and the acceleration towards the center immediately doubles, but the radial acceleration produces no radial velocity.

A great similarity exists between the circular motion and the motion of a gyroscope under constant torque and uniform precession.

II. IF THE ROTATION PRODUCED BY A TORQUE, CONSTANT OR VARIABLE, ABOUT A FIXED AXIS *PP'* IN SPACE, AND IN THE PLANE OF A THIN GYRO DISC, BE ADDED TO A UNIFORM ROTATION OF THE DISC ABOUT ITS AXLE, THE SAME INERTIA REACTION TO THE TORQUE, AND THE SAME VELOCITY RESULT, AS IF THE DISC WERE NOT ROTATING ABOUT ITS AXLE.

This is a basic experimental fact. In Fig. 3, if the weight W is released, it will reach the floor in the same time whether the disc is spinning or not about its axle AA', and the same

FIG. 3.



final velocity will result about axis DD', provided axis PP' is fixed in space, and would continue indefinitely, at constant angular velocity, if friction did not stop it.

A moment about MM' as axis (which moves with the rotation about PP'), perpendicular to PP' and in the plane

of the disc, will be contributed by every particle of the rotating disc, and will be transmitted to the axle, thence to the frame, and finally to the bearings PP', which are fixed, in final analysis, to the earth.

We will show that the above results from Newton's Laws of Motion, applied to each rotating particle. We will consider the case of Fig. 3, for uniform angular velocity $\dot{\omega}$ of the disc about the axle AA', and uniform angular velocity $\dot{\psi}$ about PP', called precessional velocity. We will follow the motion of any particle B, for a very short time t. The thin disc moves from $MDM'D'$ to $NDN'D'$. The particle B will move to E. There will be a displacement $R\dot{\omega}t$ about the axle AA', from B to D, and this displacement is the same for all particles at the radius R. There is a displacement, in precession, $\dot{\psi}tR\cos\varphi$, from B to C, on a small circle of the sphere of radius R, with DD' as poles. The precessional displacement depends on φ. The two displacements bring the particle to E. A third displacement, from E to H, is necessary to bring the particle back to the disc, at H.

There are two constraints: the disc and axle form a rigid body which does not alter its shape under the two rotations, and the axis PP', fixed in space, must always touch the disc along a diameter.

If the particle were suddenly relieved of these constraints, it would move in a plane tangent to the sphere of radius R, at the point B, and the diagram would be as in Fig. 1, (b). If the particle were constrained to slide on the inside surface of a sphere of radius R, it would move to E, where $DE = BC$. This would give rise to a reacting force towards the center, as in Fig. 2. We assume that the disc is carefully constructed of uniform material, and of revolution about the axle AA', hence this reacting centripetal force is balanced by an equal and opposite force produced by the particle diametrically opposite to B. The dynamic effect is zero, the disc is merely stressed.

To satisfy the two constraints, we need only add the displacement EH, in the direction E to H, on the sphere surface. We will calculate the displacement EH, in terms of the time t, and the angular velocities $\dot{\omega}$ and $\dot{\psi}$.

In Fig. 3, $b\,c\,d\,e\,h$ are the projections of $B\,C\,D\,E\,H$, on a plane through O, perpendicular to DD'.

$$\begin{aligned} EH = eh &= bc - hd \\ &= \psi t \times ce \\ &= \psi t \dot{\omega} t R \sin \varphi \\ &= \dot{\omega}\psi t^2 r. \end{aligned} \tag{4}$$

The displacement EH is of the second order of the time, with respect to the motion along the arc $\dot{\omega}t$, and is at right angles to the plane of the arc. Hence, if m were free to slide inside the sphere its motion from the disc would be on a parabola, tangent to the disc at C, the same condition as in Fig. 1, (c), or Fig. 2, at O. A constant force f, acting on the particle of mass m, at B, at right angles to and towards the disc, would prevent the displacement from the disc.

$$\frac{1}{2}\frac{f}{m} t^2 = \dot{\omega}\psi t^2 r, \tag{5}$$

$$f = 2m\dot{\omega}\psi r = 2m\dot{\omega}\psi R \sin \varphi. \tag{6}$$

Above MM', the forces to be supplied finally by the bearings PP', to maintain the constraints, are away from the reader, Fig. 3, (b), and below MM', the forces are towards the reader. The forces are linear with respect to the distance r of the particle from MM', see Fig. 7.

The motion HE takes place from H to E if the axis DD' were not fixed. If this motion continued in the same direction, notice that it would bring the axle parallel to the fixed precession axis DD'. The torque required to prevent this motion is in the opposite direction.

The accelerations $2\dot{\omega}\psi r$ produce no velocity; the conditions repeat themselves as in Fig. 2. The forces do no work, therefore, which agrees with the condition that the bearings PP' are fixed, and hence the reaction does no work.

The total moment about MM', due to the entire disc, is equal to the reacting torque T supplied by the fixed bearings PP'.

$$T = \Sigma fr = \dot{\omega}\psi 2 \Sigma m r^2 = 2I_1 \dot{\omega}\psi \tag{7}$$

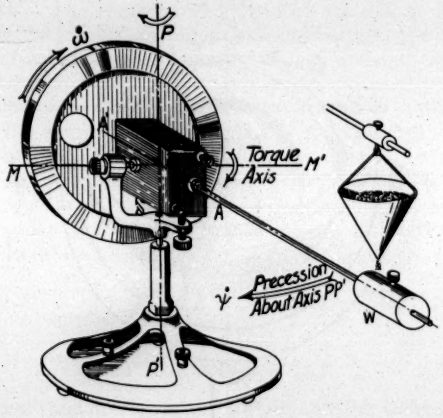
$$= I\dot{\omega}\psi, \tag{8}$$

where I_1 is the moment of inertia of the disc about a diameter MM', and $I = 2I_1$ is the moment of inertia of the disc, if thin, about its axle.

Equations (7) and (8) are true for any gyro which is a volume of revolution about its axle. The above demonstration for a thin gyro disc, will be used to prove this shortly.

If the gyro were of revolution, in the form of a ring, connected by spokes to the axle, then the torque contribution due to the spokes would depend on the angular position of

FIG. 4.



the latter. Only for a gyro of revolution, and well balanced, would the torque T be constant, for constant $\dot{\psi}$.

The energy of the system, neglecting the masses of the non-rotating parts, is

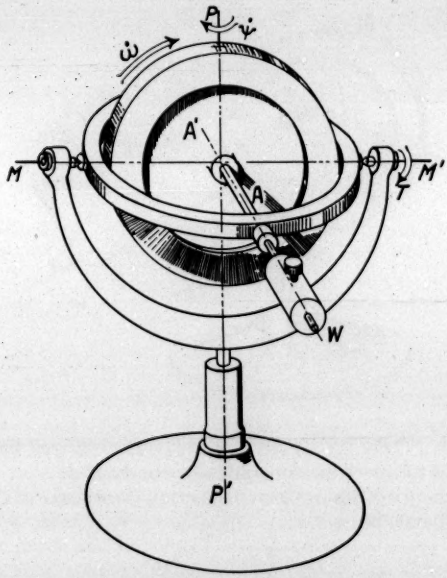
$$E = \frac{1}{2} I\dot{\omega}^2 + \frac{1}{2} I_1\dot{\psi}^2. \tag{9}$$

The second part only is built up by the falling weight in Fig. 3, hence the inertia reaction is independent of $\dot{\omega}$, and is the same if $\dot{\omega} = 0$.

Equations (7) and (8) are true if ψ varies, for equations (4) and (6) would give the instantaneous values for a given position of ψ.

In order to check equation (8) quantitatively, we designed an electrically driven gyroscope, in a form suitable for student laboratory work, and lecture room demonstration as well. The gyroscope, Fig. 4, is conveniently driven from the secondary of a 110 volt a.c. transformer. The numerable taps permit a speed variation. The axle speed is readily obtained by means of a simple tachometer. The form Fig. 5, does not

FIG. 5.



permit the use of a tachometer. A 6 volt storage battery could also be used, with a small series resistance to vary the motor speed, but the transformer is cheaper and more convenient.

By means of the counterweight which can be fixed by a thumb screw to any position on the long rod, a torque can be imposed in either direction, or reduced to zero, for a balanced gyro. Instead of imposing a precession, we impose the torque, accomplishing the same result. By suddenly imposing this torque, which is done by holding the counterweight in the hand, bringing the axle horizontal, then suddenly letting go, it will be seen that the initial motion is not in precession, but is in the direction of the torque. A motion of Nutation sets in, which is all the more pronounced the lower the speed of the gyro, see Fig. 10. This action is explained under IV. The moment of inertia of the disc is measured by using the method of bifillar suspension; and the torque by means of a balance or a spring balance, and multiplying by the lever arm.

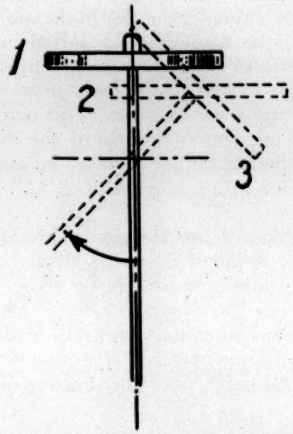
If the precession is hurried, by means of a pencil, see Fig. 9, the torque required is greater than that produced by the counterweight and hence the latter rises. Retarding the precession produces the opposite effect. The accelerations $2\dot{\omega}\dot{\psi}r$ now do produce an angular velocity about MM', Fig. 3. This angular displacement θ, and the angular acceleration $\ddot{\theta}$ are the same for all particles of the rotating disc,

$$\begin{aligned} \frac{EH}{r} = \theta &= \dot{\omega}\dot{\psi}t^2, \\ \ddot{\theta} &= 2\dot{\omega}\dot{\psi}, \\ I_1\ddot{\theta} &= T = I\dot{\omega}\dot{\psi}. \end{aligned} \tag{11}$$

Notice that in Fig. 4, the torque and the precession axes intersect the axle at the same point, but this point is not the center of gravity of the disc, as it is in Fig. 5. Equations (7) and (8) are the same, however, for uniform precession. There is a centrifugal reaction on the precession shaft, due to the precessional motion on the disc and on the counterweight. This produces a moment which either increases or decreases the gravity moment, if the heavier end is above or below the level position, respectively, but we are limiting our attention to small variations from the level position. There would be a centripetal moment in Fig. 5 also if the shaft were out of level. For high axle speeds compared to precession, the axle tilt does not affect equations (7) and (8).

To show that the effect of shifting the disc along the axle, so that its center does not coincide with the intersection of the axes, Fig. 6 is a sketch of Fig. 4, with the precessional motion appearing as a circle. It is a view from the top. We

FIG. 6.



can consider the disc to be given two displacements, from position 1 to 2, without rotating the disc, and from 2 to 3 by rotating the disc, but keeping the disc center fixed on the precession circle. The first displacement is attended by a centripetal force, and no torque, the latter by the torque as in Fig. 3. It follows that any number of thin discs can be placed on the axle, with any spacing, and the reaction to precession of all the discs will be independent of the spacing. Hence for any gyro of revolution, equations (7) and (8) give the *torque reaction* to precession. The value of $\ddot{\theta}$ and of I_2 depend on the spacing of the thin sections, and the position of each from MM' or PP'.

It is only when the motion in precession is not uniform, as during the nutational motion, that the dead masses: the motor frame, the counterweight, affect the motion. These dead masses are made as small as possible.

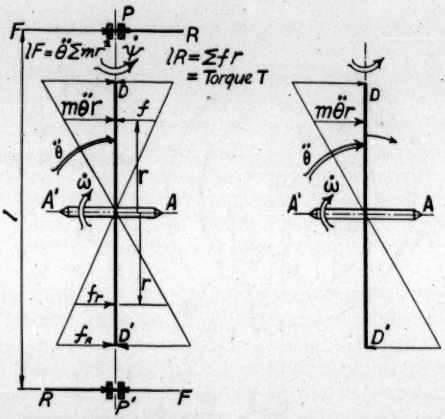
Equation (11) becomes

$$I_2\ddot{\theta} = T = I\dot{\omega}\dot{\psi}. \qquad (12)$$

where I_2 is the moment of inertia about MM' or about PP'.

In Fig. 4, the sand issuing from the cone at uniform rate causes the torque to diminish, reduce to zero, and then reverse in direction. The precession does likewise.

FIG. 7.



With constant gravity torque, the precession, once established, would continue indefinitely if there were no friction to the precession. The friction is in the precessional spindle, and in precessing the disc and its air whirl. The forces acting are very small, and in application to the gyroscopic compass, the losses are reduced considerably by enclosing the motor and disc in a vacuum.

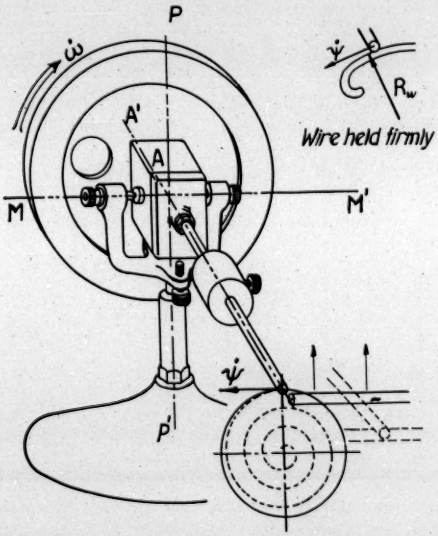
The friction retards precession, and the heavier end of the gyro dips slowly. The greater the axle speed, the slower the precession for a given torque, hence the smaller the friction, and the slower the dip. This dipping of the axle is itself a precession, just as the initial motion of nutation is, and produces a motion in the direction of the horizontal

precession. The dipping supplies the energy for the friction losses, and the kinetic energy for the precession.

III. SUDDEN REMOVAL OF THE TORQUE FROM A FREE GYRO.

In Fig. 9, with the disc not rotating, balance the gyro by setting the counterweight so that the axle remains stable in any position. The axle will remain in any position, even when the gyro is rotating. The Gyro is free.

FIG. 8.



If a pencil *P*, maintained horizontal while pushed vertically upward, against the counterweight rod, the rod will move to the left, see rule for Fig. 9.

The pencil exerts a torque, which is suddenly removed when the rod runs off the pencil. The accelerations of Fig. 3, produce an angular displacement in the opposite direction to the previously applied torque. Referring to Fig. 3, equations

(11), (12)

$$\frac{HE}{r} = \theta = \dot{\omega}\psi t^2$$

$$\ddot{\theta} = 2\dot{\omega}\psi,$$

$$I_2\ddot{\theta} = T = I\dot{\omega}\psi.$$

The angle θ is the same for all particles, thus no other forces are to be investigated, for small t, since the disc retains its shape. The addition of the two displacements, ψt and $\dot{\omega}\psi t^2$, which indicates uniform angular acceleration at right angles to $\dot{\psi}$ results in a circular motion of each point of the axle and rod. The entire axle moves in a right circular cone. The greater the torque originally applied, the greater the radius of the circle which the end of the rod describes. The condition is similar to that of Fig. 2. Notice that the acceleration, equation (11), produces no velocity towards the center. The circular motion would continue forever, were it not for friction. The greater the circular motion, the greater the friction, and the more quickly the circular motion spirals to the center of the circle.

In the expulsion of a shell from a cannon, the shell is rotated about its axis, being forced to follow the spiral grooves in the bore. On emerging, a slight change in the rush of gases from the symmetrical, a slight shift from the axial propulsion would be sufficient to impart an impulse torque, causing a right conical motion of the axis about its center of gravity. The shell length, diameter, nose shape, and angular velocity imparted, are designed by trial and error so that the wind resistance brings the nose center, and hence the axis, to the trajectory.

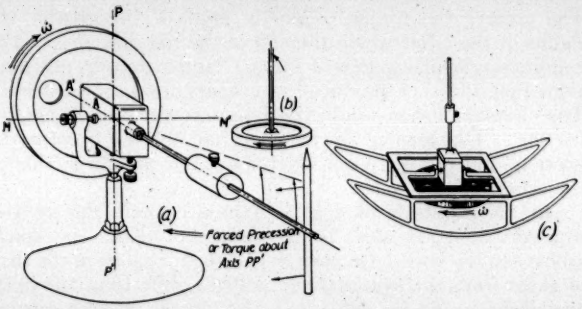
IV. FORCED, UNIFORM PRECESSION ABOUT A FIXED AXIS, IMPOSED ON A FREE GYRO.

In Fig. 9, (*a*), a forced precession imposed on a free gyro, causes the gyro axle to rise, in such a direction, that if the motion continued, the axle would take a position coinciding with or parallel to the axis of the forced precession. In this position the precession would turn the motor field and frame about the gyro axle. There is equilibrium. Fig. 3 and the explanation therewith, indicates that the above simple rule

is true. There would be equilibrium if the fixed precession axis is opposite in direction to the direction of spin of the axle; but the equilibrium is very unstable, the slightest tilt and the axle reverses its direction.

The above action forms the principle of the gyroscopic compass. Instead of having the gyroscope axle find equilibrium in a position parallel to the earth's axis of rotation, and in the same direction, the compass is so designed that the axle points to the north, but is in a horizontal plane. The motion of the ship is an additional forced precession, and

FIG. 9.



its action depends on the speed of the ship, and whether the direction is in the meridian or approximately on a circle of latitude. In the latter case the effect is zero. A change in direction of the ship would have a greater effect, since the angular velocity imposed would be greater.

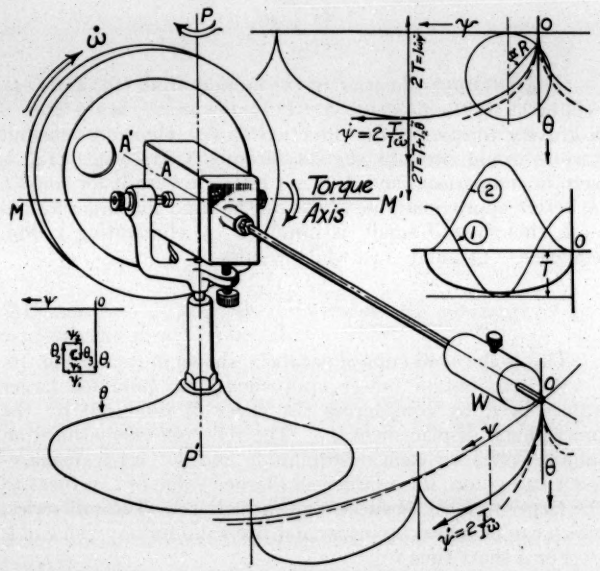
V. NUTATION. SUDDEN APPLICATION OF THE TORQUE ON A FREE GYRO.

In Fig. 10, if the counterweight is held so that the axle of the gyro is horizontal, and then suddenly let go, the axle will not precess immediately. The end of the rod moves in the cycloidal paths shown. These cycloids gradually diminish and die out, due to the friction, and uniform precession takes place. If the counterweight is merely released, with no impulse, the initial motion will be vertically downward, in

the direction of θ, that is, in the direction of the torque. This downward motion develops a motion to the left, along ψ, in accordance with the rule, which results from Fig. 3, and the discussion.

We will arrive at the motion of the axle by a process of approximations. The advantage will be in simplicity, and in better conception of the phenomena.

FIG. 10.



Instead of assuming a constant torque T, suddenly applied, consider an imposed angular displacement about the torque axis MM',

$$\theta_1 = \tfrac{1}{2}kt^2 \qquad (13)$$

under constant acceleration, and follow it for a very short time t. Never mind how the torque varies, if it does, to produce this displacement.

The direction of the displacement ψ_1, in precession, due to the displacement 13, follows the general rule, and is shown in Fig. 10. The form of the precessional displacement will be, from equation (11)

$$\psi_1 = A\,\dot{\omega} t \tfrac{1}{2} k t^2 = \tfrac{1}{2} A k \dot{\omega} t^3. \tag{14}$$

This is of the third order in t, while θ_1 is of the second order. Hence for small t

$$\frac{\psi_1}{\theta_1} \doteq 0.$$

The first approximation to the motion, from (13) and (14), will be along the tangent, vertically downward, in the case of a gravity torque, in the direction of θ_1. Hence a constant torque would produce the displacement (13), since (14) is zero in comparison, and does not interfere with it for small t. A better approximation, which can be used for larger values of t, though still small, is obtained by eliminating t from equations (13), and (14), which results in

$$\psi_1^2 = 2\frac{A^2\dot{\omega}^2}{k}\theta_1^3. \tag{15}$$

This is the semi-cubical parabola, shown dotted in Fig. 10.

We can obtain better approximations, good for larger values of t, by considering the effect θ_2 produced by the precessional displacement ψ_1. The reflected effects form an infinite series for each coördinate θ, and ψ. Each displacement can go on, for a larger and larger value of t, subject to the larger number of successive corrections. The full series, which can be added by inspection, are valid for any value of t.

For a short time t

$$\theta_1 = \tfrac{1}{2}\ddot{\theta} t^2 = \tfrac{1}{2} k t^2, \tag{16}$$

$$T = I_2 \ddot{\theta}_1, \tag{17}$$

$$T_1 = I_2 \ddot{\psi}_1 = I\,\dot{\omega}\dot{\theta}_1, \tag{18}$$

where I is the moment of inertia of the disc about its axle, and I_2 is the moment of inertia of the entire body, about MM', or about PP'. Notice that T_1 is that part of the suddenly

applied torque T, which is balanced by the disc torque, (17), *at the end of the time t.*

For $t = 0$

$$\text{Torque applied} = T,$$

$$\ddot{\theta} = \frac{T}{I_2},$$

$$T_1 = 0,$$

$$\ddot{\psi}_1 = 0.$$

At the end of a short time t,

$$\dot{\theta}_1 = kt.$$

Gradually T_1, and $\ddot{\psi}_1$ increase, during the short time t. We will obtain these values, at the end of the time t, in terms of end value of the interval t.

From (17), integrating from $t = 0$, to $t = t$,

$$\psi_1 = \frac{I\dot{\omega}}{I_2} k \int\int t dt dt \tag{19}$$

$$= \frac{I\dot{\omega}}{I_2} k \frac{t^3}{\underline{3}}. \tag{20}$$

Since $\ddot{\psi}_1 = \dot{\psi}_1 = \psi_1 = 0$ for $t = 0$, the constants of integration are zero. From (19)

$$T_1 = I_2 \ddot{\psi}_1 = I\dot{\omega} kt. \tag{21}$$

This precessional displacement ψ_1 reflects a displacement θ_2, during the time t, about the axis MM', but in the negative direction, and can be considered produced by a torque T_2

$$T_2 = I_2 \ddot{\theta}_2 = I\dot{\omega}\psi_1. \tag{22}$$

The value of T, indicates that it increases linearly with the time t, and at the end of that time, has reached the value given, equation (21).

The next term of each series will be derived, and the remainder follow by inspection of the observed law of their formation.

$$-\theta_2 = \left(\frac{I\dot{\omega}}{I_2}\right)^2 k \int\int \frac{t^2}{L^2} dt dt = k \left(\frac{I\dot{\omega}}{I_2}\right)^2 \frac{t^4}{\underline{4}}, \tag{23}$$

$$\psi_2 = \frac{I}{I_2} \int\int \dot{\omega} dt \dot{\theta}_2 dt = -k \left(\frac{I\dot{\omega}}{I_2}\right)^3 \frac{t^5}{\underline{5}}. \tag{24}$$

The θ_3 displacement is in the positive direction. The successive corrections are indicated graphically in Fig. 10.

The series, and their sum are now given. The sums are obtained by comparing the expansion of the sine, and the cosine of an angle.

$$\theta = \theta_1 + \theta_2 + \theta_3 + \cdots,$$

$$\psi = \psi_1 + \psi_2 + \psi_3 + \cdots,$$

$$\theta = \tfrac{1}{2}kt^2 - k\left(\frac{I\dot{\omega}}{I_2}\right)^2\frac{t^4}{\underline{|4}} + k\left(\frac{I\dot{\omega}}{I_2}\right)^4\frac{t^6}{\underline{|6}} - \cdots, \tag{25}$$

$$\psi = k\frac{I\dot{\omega}}{I_2}\frac{t^3}{L^3} - k\left(\frac{I\dot{\omega}}{I_2}\right)^3\frac{t^5}{\underline{|5}} + k\left(\frac{I\dot{\omega}}{I_2}\right)^5\frac{t^7}{\underline{|7}} - \cdots, \tag{26}$$

$$\theta = \frac{TI_2}{(I\dot{\omega})^2}\left[1 - \cos\frac{I\dot{\omega}}{I_2}t\right], \tag{27}$$

$$\psi = \frac{TI_2}{(I\dot{\omega})^2}\left[\frac{I\dot{\omega}}{I_2}t - \sin\frac{I\dot{\omega}}{I_2}t\right]. \tag{28}$$

Equations (27), (28) are the equations of the cycloid, plotted on a right, circular cylinder of unit radius, with PP' as axis, valid for any value of t. With no friction, these cycloidal nutations would go on forever.

The radius of the rolling circle is

$$R = \frac{TI_2}{(I\dot{\omega})^2}. \tag{29}$$

The cycloidal motion agrees with experiment. These curves can be obtained experimentally by photography. A $1/4''$ polished ball bearing is inserted in the end of the counterweight, and held with sealing wax. A horizontal band of light, in the path of the motion, can be obtained by placing a 200 watt lamp in a box, in one side of which a horizontal slit is cut.

The larger I_2, which includes the moment of inertia of the dead masses, i.e., the non-rotating masses, the larger will be the value of the radius R, for a given torque, and the larger the period of the nutation. The nutation period τ is in-

dependent of T, unless the torque affects I_2

$$\tau = 2\pi \frac{I_2}{I\dot{\omega}}. \tag{30}$$

The gyroscopic effect is lost if there is too much dead weight, or if $I\dot{\omega}$ is too small.

The maximum effect is obtained when I_2 is minimum. This is the case for a thin ring of large radius, hence large I for a given mass, and for the axis PP' passing through the center of gravity of the disc.

In this case

$$2I_2 = I. \tag{31}$$

From equations (27) and (28)

$$\dot{\theta} = \frac{T}{I\dot{\omega}} \sin \frac{I\dot{\omega}}{I_2} t, \tag{32}$$

$$\dot{\psi} = \frac{T}{I\dot{\omega}} \left[1 - \cos \frac{I\dot{\omega}}{I_2} t \right], \tag{33}$$

$\theta = 0$ for $\frac{I\dot{\omega}}{I_2} t = 0, \pi, 2\pi, 3\pi, \cdots,$

$\theta = 2\frac{T}{(I\dot{\omega})^2}$ at lowest point, for $\frac{I\dot{\omega}}{I_2} t = \pi, 3\pi, \cdots,$

$\dot{\psi} = 2\frac{T}{I\dot{\omega}}$ at lowest point. (34)

At the lowest point of the cycloid, the disc reacting torque is $2T$, and acts upward, which accounts for the rise of the axle to the initial height.

The precessional velocity is double that required to balance the torque T applied, for uniform precession.

The average precession for the cycloid equals the value for uniform precession with the torque T.

The kinetic energy of the precessional motion at θ minimum, and $\dot{\psi}$ maximum, is

$$E = \tfrac{1}{2} I_2 \dot{\psi}^2 = 2I_2 \left(\frac{T}{I\dot{\omega}} \right)^2. \tag{35}$$

The potential energy of the excess weight, converted to kinetic by the fall, or dip, is

$$T\theta = 2I_2\left(\frac{T}{I\dot{\omega}}\right)^2, \tag{36}$$

which is the same as E. At any point of the cycloid, the sum of the kinetic energy about MM', and about PP', equals the energy of the fall. A fall or dip, accompanies a precession produced by a suddenly applied torque to a free gyro.

Notice that for uniform precession, and for $\dot{\psi}$ maximum, equation (34), I_2 does not enter. In both cases $\ddot{\psi} = 0$.

At any point of the cycloid, the sum of the action and the reaction is equal to zero,

$$T + [I_2\ddot{\theta} + I\dot{\omega}\dot{\psi}] = 0, \tag{37}$$

$$T = -\left[T\cos\frac{I\dot{\omega}}{I_2}t + T\left(1 - \cos\frac{I\dot{\omega}}{I_2}t\right)\right], \tag{38}$$

where the constant torque T equals the component reaction torque $I_2\ddot{\theta}$, curve 1, Fig. 10, producing acceleration about MM', plus the gyro reaction torque $I\dot{\omega}\dot{\psi}$, curve 2, respectively, about the same axis. The curves are plotted so as to give a resultant torque of zero value at every point.

The friction in the bearings MM' and PP', and that due to the disturbing of the air stream about the disc, by the rotations about PP' and MM', dampen the nutation, and absorb energy which accounts for the slow dip of the cusps from the horizontal plane. Due to the elasticity of the system, the torque cannot be suddenly applied. The cusps lose their sharpness, and the $\dot{\psi}$ is not zero where the cusps should be, hence not so great a drop, and the curves become more shallow, and fade into uniform precession.

The forces are small, and the best results are obtained by photography as described.

The larger $I\dot{\omega}$ the smaller the precessional uniform velocity, and the slower the dip, for given friction conditions.

VI. APPLICATION OF THE TORQUE GRADUALLY, LINEARLY WITH THE TIME.

By applying the torque gradually, using sand flow, Fig. 4, the envelope of the small cycloids will be nearly parabolic.

The dip will account for the precessional energy, neglecting the friction, but it will not be double the value necessary, for suddenly applied torque.

The method of obtaining the equations of motion, is the same as above for constant T.

The initial, imposed motion is

$$\theta = q\frac{t^3}{L^3}, \tag{39}$$

$$I_2\ddot{\theta} = qt. \tag{40}$$

The series obtained can be added

$$\theta = -\frac{qI_2^2}{(I\dot{\omega})^3}\sin\frac{I\dot{\omega}}{I_2}t + \frac{qI_2}{(I\dot{\omega})^2}t, \tag{41}$$

$$\psi = -\frac{qI_2^2}{(I\dot{\omega})^3}\left(1 - \cos\frac{I\dot{\omega}}{I_2}t\right) + \frac{qt^2}{2I\dot{\omega}}. \tag{42}$$

The period is the same as for applying any value of T suddenly.

The experiment shows no periodic motion, for $I\dot{\omega}$ large, since then the coefficients of the periodic functions are small compared to the coefficients of t. For t small the periodic functions are also small. Neglecting the periodic terms, we obtain

$$\theta = \frac{qt^2}{(\omega I)^2}t, \tag{43}$$

$$\psi = \frac{q}{2I\dot{\omega}}t^2, \tag{44}$$

which are the equations of the parabola

$$\theta^2 = \frac{2I_2^2}{(I\dot{\omega})^3}\psi, \tag{45}$$

which indicates an initial motion downward.

SUDDEN REMOVAL OF A CONSTANT TORQUE T.

This case was considered under III. The process of reflected effects can be applied to this case.

$$\psi = B, \text{ constant} = \frac{T}{I\dot{\omega}}, \tag{46}$$

$$I_2\ddot{\theta}_1 = I\dot{\omega}B,$$

$$\theta_1 = \frac{I}{I_2}\int\int \dot{\omega}dtBdt = B\frac{I\dot{\omega}}{I_2}\frac{t^2}{\underline{|2}},$$

$$\psi_1 = -\frac{I}{I_2}\int\int \dot{\omega}dtB\frac{I\dot{\omega}}{I_2}tdt = -B\left(\frac{I\dot{\omega}}{I_2}\right)^2\frac{t^3}{\underline{|3}}.$$

Adding the series

$$\theta = \frac{TI_2}{(I\dot{\omega})^2}\left[1 - \cos\frac{I\dot{\omega}}{I_2}t\right], \tag{47}$$

$$\psi = \frac{TI_2}{(I\dot{\omega})^2}\sin\frac{I\dot{\omega}}{I_2}t. \tag{48}$$

Equations (47), (48) represent a circle, which can be obtained by eliminating t

$$\psi^2 + \left[\theta - \frac{TI_2}{(I\dot{\omega})^2}\right]^2 = \left[\frac{TI_2}{(I\dot{\omega})^2}\right]^2. \tag{49}$$

The radius of motion of the axle, on a sphere of unit radius, is

$$R = \frac{TI_2}{(I\dot{\omega})^2}, \tag{50}$$

see Fig. 8.

If a wire, Fig. 8, is gently pushed against the counterweight rod of a *free* gyro, and then held firmly fixed in space, the impulse develops a slow precession, which is continued because the wire supplies a reacting torque necessary. The rod will follow the wire if the radius is larger or equal to the radius, equation (50), corresponding to the impulse. If the radius of the wire at any point is smaller the rod will leave the wire. Friction alters the conditions; instead of a continuous circular motion, there is a spiral motion. The greater the speed the quicker the spiral motion brings the axle to rest. The spiral motion can cause the rod to return to the wire, and will continue or reverse its motion along the wire, depending on the angle of contact, on the return.

The pressure exerted on the wire depends on the difference of the radii discussed.

From (47)

$$\ddot{\theta} = \frac{I}{I_2}\cos\frac{I\dot{\omega}}{I_2}t. \tag{51}$$

For $t = 0$

$$I_2\ddot{\theta} = T, \tag{52}$$

which is the same as equation (46), as it should be. The torque T which produced $\psi = B$ just before it was removed, reappears as a centrifugal torque to balance $\psi = B$.

From (46)

$$T^2 = (I\omega B)^2. \tag{53}$$

From (50)

$$T = \frac{(I\dot{\omega})^2}{I_2}R, \tag{54}$$

whence

$$T = T_c = \frac{I_2B^2}{R}. \tag{55}$$

If the radius of curvature of the wire is R_w, the centrifugal torque is

$$T_c = \frac{I_2B^2}{R_w}. \tag{56}$$

The torque producing pressure on the wire, is for a given B

$$T_p = I_2B^2\left[\frac{1}{R} - \frac{1}{R_w}\right]. \tag{57}$$

The reaction of the wire, plus the centrifugal torque, maintains the initial precession B, a constant.

For $R_w = \infty$,

$$T_p = \frac{I_2B^2}{R} = T,$$

in absolute value, but T_p is opposite in sign, since it is the reaction which is in the direction of T.

VII. THE GYROSCOPIC PENDULUM. THE TOP.

A gyro pendulum, Figs. 12, 13, if the disc is not rotating, for small angular motion θ, measured from the precession

FIG. 11.

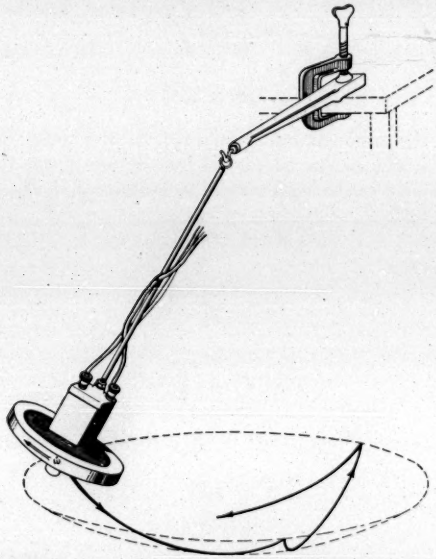


FIG. 12.

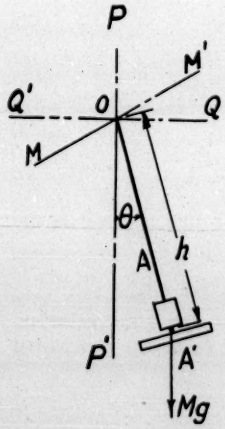
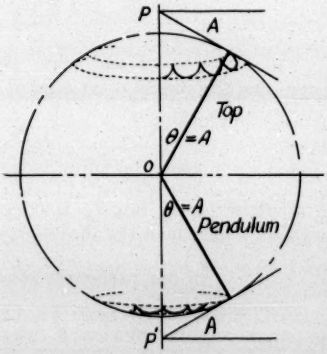


FIG. 13.



axis OP', the equation of motion is

$$I_2\ddot{\theta} + Mgh\theta = 0. \tag{58}$$

If the time is measured for a deflection

$$\theta = A, \qquad t = 0.$$

then

$$\theta_1 = A \cos \sqrt{k}t, \tag{59}$$

where

$$k = \frac{Mgh}{I_2} = \frac{T}{I_2}.$$

This is the initially imposed motion.

For a top, the angle θ_1 is measured from OP, and instead of (58), we have

$$I_2\ddot{\theta} - Mgh\theta = 0 \tag{60}$$

and

$$\theta_1 = A \operatorname{Cosh} \sqrt{k}t. \tag{61}$$

Since we are considering only shallow nutations, the imposed motion considered will be sufficiently accurate if we use the first two terms of the expansion, of (52) and (54)

$$\theta_1 = A\left[1 \pm \frac{kt^2}{\lfloor 2}\right]. \tag{62}$$

The + sign for the top, and the minus sign for the pendulum. The motion will be limited to near the deflection A, or the top of the cos or Cosh curve. The simplification amounts to considering the motion to be on a cone, tangent to the sphere on the circle of diameter $2A$, with PP' as axis; or at any instant the motion can be considered to be on a tangent plane to the cone. The case considered of suddenly applying a constant torque, for shallow nutation, amounted to considering the motion to be on a cylinder, with PP' as axis, the cylinder being tangent along the equator.

The equations (62), of the imposed initial motion, are the same, except for the sign, and the constant term, as the imposed motion for the suddenly applied constant torque, where θ_1, in Fig. 10 was considered to be a small angular motion near the equator.

We can write the equations for the pendulum

$$\theta = A - \frac{TI_2}{(I\dot{\omega})^2}\left[1 - \cos\frac{I\dot{\omega}}{I_2}t\right], \tag{63}$$

$$\psi = -\frac{TI_2}{(I\dot{\omega})^2}\left[\frac{I\dot{\omega}}{I_2}t - \sin\frac{I\dot{\omega}}{I_2}t\right]. \tag{64}$$

For the top

$$\theta = A + \frac{TI_2}{(I\dot{\omega})^2}\left[1 - \cos\frac{I\dot{\omega}}{I_2}t\right], \tag{65}$$

$$\psi = +\frac{TI_2}{(I\dot{\omega})^2}\left[\frac{I\dot{\omega}}{I_2}t - \sin\frac{I\dot{\omega}}{I_2}t\right]. \tag{66}$$

The discussion is exactly the same as for case V.

The period of the pendulum, with the disc not rotating, is

$$\tau_1 = 2\pi\sqrt{\frac{I_2}{T}} = 2\pi\sqrt{\frac{I_2}{Mgh}}. \tag{67}$$

The period of precession, one turn, is

$$\tau_2 = 2\pi\frac{I\dot{\omega}}{T} = 2\pi\frac{I\dot{\omega}}{Mgh}. \tag{68}$$

The ratio

$$\frac{\tau_2}{\tau_1} = \frac{I\dot{\omega}}{\sqrt{T}} = \frac{I\dot{\omega}}{\sqrt{Mgh}}. \tag{69}$$

These periods are easily checked experimentally.

In both cases above, the motion is a cycloid. For the pendulum it is towards the axis OP', and for the top, away from the axis OP. In both cases the cusps are on the $\theta = A$ radius circle of the sphere.

The Gyroscopic Stabilizer, is similar to the case of the pendulum, except that the moment of inertia is not the same about the axes MM', and QQ', and there are two centers on PP', one for the pendulum or gyro, the other for the boat.

We have avoided the simultaneous differential equations usually considered. We have avoided the study of instantaneous axes, and of component angular moments of momentum, which render the subject difficult.

A sufficient number of phenomena were considered, in a simple, yet rigorously correct manner, and probably affording a better insight of the phenomena. The results are readily subject to experimental verification, in a quantitative manner, with the apparatus designed.

With this analytical and experimental foundation, the undergraduate can read with understanding the larger treatises on gyroscopic effects, and the applications of the gyroscope can be understood.

The author thanks Mr. Philip H. Courrier, of the Scientific Apparatus Co., for valuable suggestions, and for applying his skill in the design of the apparatus.

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NEW YORK, N. Y.

Speed.—Reading recently that a racing plane had attained a speed of 406.9 miles per hour, one is prone to wonder whether there is an upper limit to these human-attainable velocities. Some facts pertinent to such speculations are brought forth through the medium of Science Service. At Langley Field, Va., is the world's highest speed wind tunnel in which air velocities as high as 800 miles per hour can be attained—faster than sound itself. A section of a racing airplane wing placed in this air stream shows an enormously increased resistance at air speeds around 600 miles per hour. If this handicap (if it can be considered as such) is to be overcome some new type of wing structure will be necessary in order to minimize further the retarding drag of the air stream. However, pilots probably will not worry just yet over this situation since they still have a leeway of about 200 miles per hour to work on.

It is pointed out that even now the tip of a propeller rotating 1800 times per minute travels at a rate of about 600 miles per hour. Wind tunnel tests show that at speeds near the velocity of sound a propeller hinders more than it helps. There is also the question of the effect of high speeds upon the human body. No doubt the greatest dangers lie in sudden changes in speed and direction. It is questionable that a pilot could withstand more than 300 miles an hour on sharp turns. Much higher straight-away speeds would be safe if acquired and lost gradually. C.

Forest Fire Damages.—(U. S. Dept. of Agric. Clip Sheet No. 732.) Comparative measurements on burned and unburned long leaf pine areas in North Carolina show that annual burning over retards the growth of trees. On the unburned plot the trees grew 19 per cent. faster in height, 9 per cent. faster in diameter, and 22 per cent. faster in volume.

A forest fire sweeping the winter grazing grounds of deer in the Lassen National Forest in California is held responsible for the death by starvation of many animals last winter, the yearling fawns suffering in particular. Deer on unburned areas nearby were found to be in good condition. C.

ABSORPTION IN ELECTRIC CONDENSERS.

BY

R. E. W. MADDISON, B.Sc., Ph.D.,

Standard Telephones and Cables, Ltd.

The total charging current entering a condenser to which a constant potential is applied is usually considered to consist of three parts:

1. The normal charging current $i_1(t)$ which flows during the charging of the geometric capacity of the condenser.
2. The anomalous charging or absorption current—$i_2(t)$.
3. The normal conduction current—i_3—which is constant.

The total current I is therefore—

$$I = i_1(t) + i_2(t) + i_3.$$

The value of i_1, which falls to a negligible amount in a very small period of time, can be calculated. In the case of a condenser having a paraffin wax-paper or other solid or liquid dielectric, current continues to flow after the normal charging current has ceased, and at a rate which is a decreasing function of time. In practical condenser manufacture, the absorption, or electrification as it is termed, is calculated from the expression—

$$\frac{(I_1 - I_2)}{I_1}, \qquad (1)\ ^{1}$$

where

I_1 is the value of the current flowing through the condenser at the end of 1 minute,

and I_2 is the value of the current flowing through the condenser at the end of 2 minutes,

the condenser throughout the test having a steady potential

[1] See Appendix.

applied to its terminals.[2] Long before the end of the first minute the normal charging current has become a negligible quantity, so that what is measured during the insulation test is in effect $i_2(t) + i_3$.

In Fig. 1, various current-time curves have been drawn. Curve I depicts the curve obtainable with a perfect condenser, i.e. one not exhibiting absorption, where the whole current is accounted for by the normal charging current and the normal conduction current. Curve II relates to a condenser exhibiting absorption and having very high insulation resistance. Curve III relates to a condenser having a good insulation resistance and moderate electrification; it is the type exhibited by the average paraffin wax-paper dielectric condenser, which if properly manufactured possesses at room temperature an insulation resistance of several thousand megohm-microfarads, determined at the end of one minute, and a positive electrification of 20–40 per cent., determined between one and two minutes. Curve IV relates to a condenser having low insulation resistance and low electrification. On applying expression (1) to curves II and IV, it will be seen that it is possible for the same electrification (some relatively low value) to be exhibited by condensers having a high or a low insulation resistance. From the discussion further on in this paper, it would seem desirable for condensers of the type under consideration to possess low electrification and high insulation resistance. In practice, however, it is found that for given raw materials (paper and impregnating compound) and a given manufacturing process, low/high values of insulation resistance are generally accompanied by low/high values of electrification. The only use of the electrification test commercially is to serve as a check on the uniformity of the

[2] Galvanometer deflections are usually employed for this calculation. Expression 1 then becomes:

$$\frac{d_1 - d_2}{d_1}, \qquad (2)$$

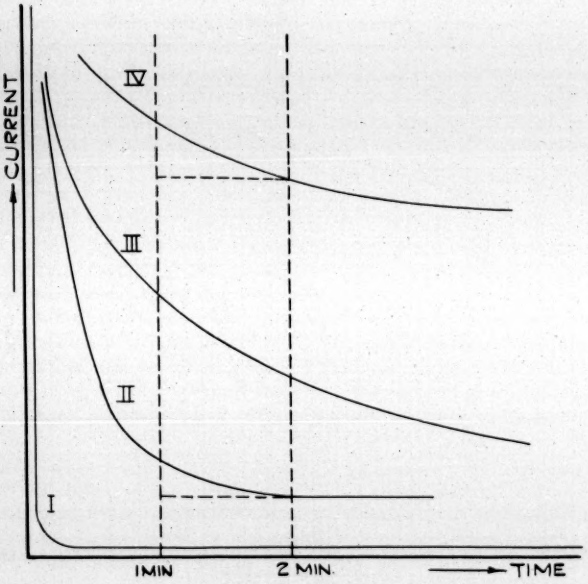
where d_1 and d_2 are the deflections produced by the currents I_1 and I_2. Substituting the resistance values corresponding to I_1 and I_2 we have

$$\frac{r_2 - r_1}{r_2}, \qquad (3)$$

where r_1 is the insulation resistance of the condenser at the end of 1 minute, and r_2 is the insulation resistance of the condenser at the end of 2 minutes.

manufactured product. It is a matter of experience that the insulation resistance and electrification are affected by the degree of dryness of the dielectric in the completed condenser. A good condenser unit, if exposed to a humid atmosphere, will rapidly deteriorate in respect of insulation resistance,

FIG. 1.



Typical absorption curves.

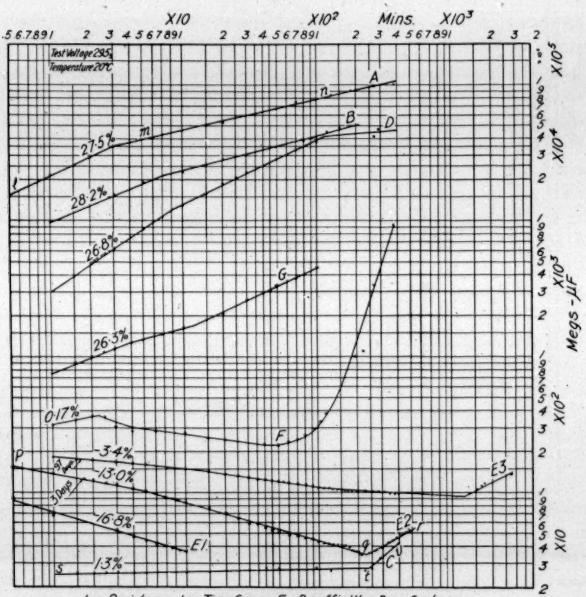
power factor, and electrification; and the last-mentioned quality as determined in the usual manner will even become negative.

On Fig. 2 are shown log. insulation resistance–log. time curves for various condensers of the paraffin wax-paper variety. Curves *A*, *B* and *D* are typical of those exhibited by condensers of high insulation resistance; curve *E* exhibits

the negative electrification just mentioned. Further reference to these curves will be made later.

The various theories that have been put forward to explain the anomalous properties of dielectrics have been summarized by L. Hartshorn (1) and are too well-known to

FIG. 2.



Log Resistance - Log Time Curves For Paraffin Wax-Paper Condensers
Percentage Value Over Each Curve Gives Electrification
Determined Between 1 & 2 Minutes

need recapitulation here. Recently, E. J. Murphy and H. H. Lowry (2) have discussed these anomalous properties with reference to the presence of free ions, adsorbed ions, and neutral molecules within the dielectric. Electrolytic material is always present in dielectrics, and in contact with moisture

it dissolves, thereby forming a conducting solution which adversely affects the electrical properties of the dielectric. In the case of moisture-absorbing dielectrics (e.g. textiles, paper, etc.), a possible explanation of their electrical behavior is afforded by assuming that conduction takes place through water occupying the spaces which exist between the insulating micelles of the dielectric proper (3). The existence of these spaces between the insulating micelles is considered to be part of the normal structure of the dielectric, and the system has been aptly called an "interstitial conduction system" in consequence of the presence of these conducting paths disseminated throughout the material (2 and 3). The anomalous charging current is considered to consist of component charging currents resulting from the redistribution of adsorbed ions on the surface of the insulating micelles of the dielectric, together with contributions from free ions as well as molecules. Furthermore, electrode reactions producing high resistance layers at the electrodes are considered to contribute to the anomalous charging current.

The decrease in insulation resistance of moisture containing dielectrics when measured with increasing values of applied potential was attributed by S. Evershed (4) to electrokinetic spreading of the water distributed throughout the material. R. R. Williams and E. J. Murphy (5) however do not consider that electrokinesis provides the only explanation of the Evershed effect. Whilst not denying that electrokinesis can occur, they consider that in the case of moist textile materials analogy with the behavior of an electrolytic cell explains certain phenomena not accounted for by the Evershed effect. In this connection it is of interest to direct attention to the work of K. Lark-Horovitz on the electromotive behavior of thin paraffin films (8), as having a possible bearing on this subject.

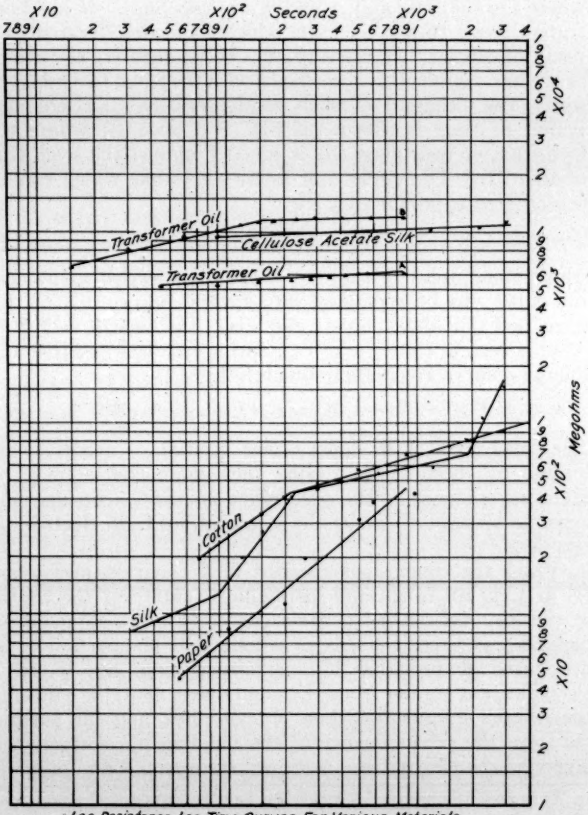
Evidence against the viewpoint of S. Evershed (and H. Stäger (9)) is adduced by M. Michailov (7) who has observed that in the case of impregnated fibrous dielectrics (paraffin waxed paper or presspahn) the weight increase of a sample on exposure to a moist atmosphere is the same as for the material in the unimpregnated state, so long as sufficient time is allowed for equilibrium to be reached. He concludes from

this that the deterioration in electrical properties of impregnated fibrous dielectrics takes place as a result of moisture absorption in the basic material, i.e. the cellulose, rendering it conducting, and not as a result of the formation of conducting paths by the condensation of moisture in the pores and capillaries in the gross structure of the material. On impregnating fibrous material these pores and capillaries are filled to varying extents, and the surface area of the cellulose in contact with the atmosphere is reduced; the result is to decrease only the velocity of moisture absorption, and not its extent. In the case of materials impregnated with paraffin wax, which has a crystalline structure, moisture readily penetrates the microscopic fissures produced by contraction of the wax on cooling and solidifying. Penetration of moisture into the body of the composite dielectric is aided by the cellulose fibres exposed on the outside.

Before returning to a consideration of the curves on Fig. 2, it will be of interest to consider similar curves (log. resistance–log. time) which have been plotted from the results of other workers and relate to certain raw materials. On Fig. 3 are shown the results R. R. Williams and E. J. Murphy (5) obtained on cotton, silk, paper and cellulose acetate silk, at a relative humidity of ca. 97 per cent. and a voltage of 275. These authors ascribe the increase in resistance "to substantial denudation of some intermediate portion of the fibre of electrolytic impurities which in general tend to accumulate in the vicinity of the electrodes. The phenomenon involves the possibility of chemical reactions between the products of the electrolysis and the material of the electrodes, as well as the evolution of gases, and the conversion of soluble salts into insoluble products." Curves *A* and *B* have been plotted from some results of D. H. Black (10) dealing with the effect of moisture on transformer oil at a voltage of 144 and a temperature of 60° C. Curve *A* shows the log. resistance–log. time relationship after the oil had been exposed to moisture for 60 hours; and curve *B* after 16 hours' vacuum drying of the oil after the exposure. He considers that the main effect of the moisture is to reduce the value of the contact resistances formed at the electrodes in consequence of the passage of current through the oil.

The considerations made in the papers (1–5) mentioned relate to the normal decrease of the anomalous charging current with time, which in general can be represented by an

FIG. 3.



Log Resistance-Log Time Curves For Various Materials

expression of the form—

$$I = At^{-n}$$

or better

$$I = \sum At^{-n},$$

where t is the time and A and n are constants. It has been stated above that condensers which have deteriorated as a result of exposure to moisture can exhibit negative electrification when examined in accordance with the usual two minutes' test. The behavior of such condensers over an extended period of time is shown on Fig. 2 (Curve E) where the logarithm of resistance (R) is plotted against the logarithm of time (t). The curve first follows a course which can be represented approximately by

$$R = kt^{-m},$$

where k and m are constants. Careful inspection shows that the curve can be separated into several parts, each of this form, and that the complete curve is of the form $R = \sum kt^{-n}$. After a certain time the electrification becomes positive and follows a curve given approximately by

$$R_1 = k_2 t^{+q}.$$

The small changes in slope, either positive or negative, exhibited by these curves during their main course, may be taken as evidence of the occurrence of component charging currents brought about by the setting up of fresh electrolytic reactions.[3]

From the conclusions reached in the papers mentioned (2, 3, 4, 5, 10) it appears justifiable to interpret the course of the log. resistance–log. time curves (Fig. 2) obtained on paraffin wax-paper condensers as follows. The portion lm of the curve A provided by condensers exhibiting positive electrification results from the component charging currents contributed by adsorbed ions or molecules, and the portion mn from the predominence of the building up of resistance layers at the electrodes. A steady state would no doubt be

[3] The word "Electrolytic" is used here in its widest sense to include reactions brought about in any manner as a result of the presence of impurities in the dielectric.

reached after the lapse of sufficient time. The flat portion *st* exhibited by curve *C* results from the presence of moisture in sufficient quantity to allow the predominence of a pure conduction current, as well as to prevent the formation or reduce the value of the high resistance layers which tend to form; the portion *tv* is realized when polarization effects occur. A change from the flat curve exhibited by the initial portion of curve *C* to the steeper sloped curve *A* in consequence of the removal of very small amounts of moisture has been recorded by D. H. Black (10) (v. supra.).

Considering now the shape of curve provided by condensers exhibiting negative electrification, the gradual decrease in resistance in the range *pq* (Curve *E*) is explained as follows. A condenser unit exposed to a humid atmosphere condenses on its surface moisture which penetrates relatively slowly into the interior of the dielectric. The application of a potential difference to the electrodes is considered to accelerate the distribution of moisture throughout the dielectric, thereby producing current conducting paths, and decreasing the resistance of the dielectric layer separating the electrodes. There is also the possibility that existing contact resistances formed in the previous history of the condenser are being removed. Simultaneously there takes place an endosmotic process—a migration of electrolytic material to the electrodes —coupled with polarization effects at the electrode surfaces. When the polarization with its attendant formation of high resistance layers predominates, then the electrification becomes positive and the portion *qr* of the curve is realized. Curves E_1, E_2 and E_3 were obtained on the same condenser; E_2 three days after E_1, and E_3 ninety-seven days after E_2. The increase in resistance exhibited by the condenser on repeating the test, and in spite of standing idle in the meantime, points to the irreversible nature of some, at least, of the polarization phenomena occurring. The increase of the electrification value in a positive direction suggests that by further prolongation of the tests, curves similar to *C* and *D* might be realized.

It is possible for negative electrification to develop in a condenser which is perfectly sealed from the influence of an external humid atmosphere. The removal of moisture from

the condenser unit during the drying prior to impregnation, may be divided into two parts (1) removal of absorbed moisture—a process which is easy to carry out, and (2) removal of adsorbed moisture—a process which can be extraordinarily difficult even with the aid of a high vacuum. A condenser unit after it has been dried, impregnated, and perfectly sealed, may show all the characteristics of a good condenser as far as can be determined by the usual electrical tests, and yet after storage for some time (1–6 weeks) it will exhibit negative electrification. The view is advanced that the adsorbed moisture still remaining in the condenser causes this negative electrification by gradually diffusing out into the dielectric, when the sequence of events is as described in the previous paragraph.

The condenser which provided curve *F* was evidently in a state intermediate between those which gave curves *E* and *G*. For the first two minutes the electrification was just positive; it then became unsteady, fluctuating between positive and negative values, but being in the main negative. This behavior seems to be consistent with the presence in the dielectric of moisture in an amount just able to upset the normal behavior (Curve *A*) of the dielectric when under the influence of a potential difference. When resistance layers are capable of being formed, the insulation resistance of the condenser increases at a very rapid rate, and attains a value exhibited by normal condensers.

It is convenient to mention at this point that the phenomenon of negative electrification is, in the experience of the present writer, rarely met with in mica condensers; it is apparently peculiar to impregnated fibrous dielectrics.

In condensers of the solid or liquid dielectric type, the dependence of the absorption phenomena on the presence of electrolytic impurities cannot be disputed. The harmful effects are increased if this electrolytic material can dissolve through the presence of moisture. Air condensers exhibit very low absorption, and what absorption they do show results mainly from the presence of small amounts of solid insulating material used to support or separate the electrodes. The indication is that improvement in the quality of commercial condensers of the type under discussion might be

brought about by extensive purification of the raw materials (paper and wax) to remove electrolytic impurity; by better removal of moisture during manufacturing processes so as to reduce the influence of the electrolytic material present by diminishing the facility for the formation of conducting solutions; as well as by adequate protection from subsequent absorption of moisture. The ideal resistance-time curve for these condensers to possess would be a straight line parallel with the time axis, corresponding to the true D.C. resistance of the dielectric, and resulting from the absence of material which gives rise to component charging currents and yields the familiar absorption curve. The straight line exhibited by curve *C*, Fig. 2, caused by the presence of moisture in the dielectric preventing the build up of the usual high resistance is undesirable.

Returning to the results of R. R. Williams and E. J. Murphy (5) we find that the materials recorded on Fig. 3 have the following properties when tested at a relative humidity of 97 per cent.

Material.	Water Content.	Electrification.*	Resistance.†
Cellulose acetate silk	7%	3.2%	9,300 megohms
Cotton	16	60	17.8
Silk	24	63.5	10.8
Paper (variety not stated)	(Not stated)	76	4.9

* Calculated from Fig. 3.

† Separation between electrodes $\frac{1}{8}$".

Time—one minute. Voltage—275.

In the case of these results, we find that a high moisture content of the material is accompanied by a high electrification, and low insulation resistance; and a low water content by low electrification and high insulation resistance. On the other hand, from the tests on ordinary condensers, we find that exposure to humidity, equivalent to an increase in the water content of the material, lowers the electrification. The absolute amount of free moisture contained in good or bad paraffin wax-paper condensers is quite low, probably less then 1 per cent., so that in this case we can speak only of relatively low or relatively high moisture content. For good condensers,

on the usually accepted standards, a relatively low moisture content is accompanied by high electrification and high insulation resistance; and relatively high moisture content by low electrification and low insulation resistance. Comparing the effect of moisture on condensers with its effect as observed by R. R. Williams and E. J. Murphy on textiles exposed to a high relative humidity, we have the confliction that an increase in the moisture content decreases the electrification in the first instance, and increases it in the second. This finds an explanation in that the mechanism responsible for the electrification is different in the two instances (2). In condensers where the water content is extremely low, the electrification is set up by (1) the displacement of adsorbed material producing charging currents which predominate over the conduction current of the dielectric, (2) the formation of contact resistances at the electrodes, and (3) the normal conduction current. A small increase in the water content has the effect of preventing the formation of contact resistances (10), as well as influencing the time of relaxation of the adsorbed material, so that the rate of increase in resistance and therefore the value of the electrification are reduced. With high water content, as obtains in textiles exposed to high relative humidities, the conduction current predominates over the displacement current contributed by adsorbed material, and the electrification is caused by the building up of high resistance layers consequent upon the electrolysis of the aqueous conducting solution present in the textile.

In consequence of the formation of non-uniform resistance layers in the dielectric separating the electrodes, a non-uniform distribution of potential will take place. The effect of this may now be considered in connection with the breakdown of condensers which have deteriorated through the absorption of moisture. The products of electrolysis produced by the passage of current through a moisture-containing dielectric will undoubtedly contain gases liberated at the surfaces of the electrodes. The formation of gaseous products having a dielectric constant almost unity and much less than that of the dielectric material proper, provides an additional source of non-uniform potential distribution between the electrodes. The presence of gases in dielectrics is well known

to have a harmful effect, especially when they are in a moist state, if the potential drop across the dielectric is sufficient to cause a glow discharge to take place within the gas bubbles. The dielectric becomes damaged both electrically and mechanically so that sooner or later breakdown occurs. On examining condensers of the metal foil-wax-paper type which have broken down through being subjected to an oscillatory discharge in spark quench circuits, it is noticed that very often the breakdown has occurred on the outermost turns, where it would be expected if moisture absorption resulting from imperfect protection of the condenser from the external humid atmosphere is a primary cause of dielectric deterioration. In condensers in which discharge phenomena have taken place, it is often found that they have occurred in the contact layers between the metal and the paper, that is to say, in the immediate vicinity of the electrodes.[4] It is stated by F. A. Schäfer (6) that the glow discharge is greater when using tin foil than when using aluminium foil electrodes in condensers, other conditions remaining the same. This is significant in view of the observation of E. J. Murphy and H. H. Lowry (2 and 3) that the polarization effects in the case of moist textiles are dependent upon the nature of the electrode material, and are caused by localized increases in the resistance of the dielectric in consequence of electrolytic changes.

SUMMARY.

1. The phenomena of positive and negative electrification in condensers of the paraffin wax-paper type are discussed in the light of recent work on current conduction in textiles and insulating oil.

2. The harmful effect of electrolytic reactions on the ability of such condensers to withstand electric breakdown is discussed.

[4] Discharge phenomena can take place also in the body of the dielectric and not at the electrode surfaces, if air bubbles are present in the dielectric in consequence of imperfect impregnation. Breakdown may occur as a result of non-uniformity of the dielectric, and the development of hot-spots (11).

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9. H. STÄGER. See Kolloidchemische Technologie (Liesegang), p. 287.
10. D. H. BLACK. Phil. Mag., **6**, 369 (1928).
11. H. STÄGER. Elektrotechnische Isoliermaterialien, p. 172.

APPENDIX.

(*a*) Expression (1) may be derived as follows. Let I be the current flowing at any instant through a condenser to which is applied a constant potential. If the logarithm of current is plotted against time, the tangent of the angle of slope of the curve at any point is

$$-\frac{d \log_e I}{dt} = \beta.$$

The average value of β between the times, t_1 and t_2 is

$$\begin{aligned}
\beta_{av} &= \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \beta dt \\
&= -\frac{1}{t_2 - t_1}\int_{I_1}^{I_2} d \log_e I \\
&= -\frac{1}{t_2 - t_1}\log_e \frac{I_2}{I_1}.
\end{aligned}$$

$$\epsilon^{-\beta_{av}(t_2 - t_1)} = \frac{I_2}{I_1}$$

$$1 - \epsilon^{-\beta_{av}(t_2 - t_1)} = \frac{I_1 - I_2}{I_1}.$$

Expanding, we have—

$$1 - \left[1 - \beta_{av}(t_2 - t_1) + \frac{\beta_{av}^2(t_2 - t_1)^2}{2!} \cdots\right] = \frac{I_1 - I_2}{I_1}.$$

As a first approximation—

$$\beta_{av}(t_2 - t_1) = \frac{I_1 - I_2}{I_1}.$$

(*b*) Commercially, condenser units are provided with a terminal plate consisting of some insulating material such as ebonite, presspahn, bakelite or the like, to which the electrodes of the condenser are connected. The effect of connecting this terminal plate across the condenser unit is equivalent to putting a very small condenser in parallel with the condenser proper. The capacity of the terminal plate in comparison with that of the condenser unit may usually be neglected, so that the terminal plate may be regarded as a resistance shunting the condenser.

It is of interest to examine what influence the value of this shunting resistance has upon the electrification as determined in accordance with the usual manufacturing insulation test. When this test is being performed the condenser with its terminal plate may be considered equivalent to two resistances R and r_t connected in parallel, where R is the constant resistance between the terminals of the terminal plate and r_t is the resistance of the condenser unit at any given time, after the application of a steady potential. The value of r_t is determined by the absorption characteristic of the condenser.

Let r be the value of the insulation resistance of the condenser at the end of one minute, $r + \Delta r$ be the value of the insulation resistance of the condenser at the end of two minutes.

Then the value of the electrification of the condenser unit in the absence of its terminal plate (the shunting resistance R) will be:

$$\frac{\Delta r}{r + \Delta r}.$$

Let ρ be the equivalent resistance of R and r_t in parallel. Then the value of ρ at the end of 1 minute will be:

$$\rho_1 = \frac{rR}{r + R}$$

and at the end of two minutes,

$$\rho_2 = \frac{(r + \Delta r)R}{(r + \Delta r) + R}.$$

The value of the electrification β will be $\frac{\rho_2 - \rho_1}{\rho_2}$

$$= \frac{R\Delta r}{r^2 + r\Delta r + rR + R\Delta r}$$

$$\frac{1}{\beta} = \frac{r^2}{R\Delta r} + \frac{r}{R} + \frac{r}{\Delta r} + 1.$$

When

$$R = 0, \qquad \frac{1}{\beta} = \infty \qquad \text{and} \qquad \beta = 0.$$

When

$$R = \infty, \qquad \frac{1}{\beta} = \frac{r}{\Delta r} + 1, \qquad \text{and} \qquad \beta = \frac{\Delta r}{r + \Delta r}.$$

Let $R = nr$, where n is a positive fraction or integer. Then

$$\frac{1}{\beta} = \left(\frac{r}{\Delta r} + 1\right)\left(\frac{1}{n} + 1\right).$$

When

$$n = \frac{1}{2}, \qquad \beta = \frac{1}{3}\left(\frac{\Delta r}{r + \Delta r}\right).$$

When

$$n = 1, \qquad \beta = \frac{1}{2}\left(\frac{\Delta r}{r + \Delta r}\right).$$

When

$$n = 10, \qquad \beta = \frac{10}{11}\left(\frac{\Delta r}{r + \Delta r}\right).$$

When

$$n = \infty, \qquad \beta = \frac{\Delta r}{r + \Delta r}.$$

A minimum value of 20 per cent. at 15° C. is commonly specified for the value of the electrification of paraffin wax-paper condensers. A condenser unit possessing this value for the electrification will have it reduced to the value shown below when the insulation resistance between the terminals

on the terminal plate bears the ratio 'n' to the insulation resistance of the condenser unit at the end of 1 minute: When

$$n = 0, \quad \beta = 0\%$$
$$n = \tfrac{1}{2}, \quad \beta = 6.6\%$$
$$n = 1, \quad \beta = 10\%$$
$$n = 2, \quad \beta = 13.3\%$$
$$n = 5, \quad \beta = 16.7\%$$
$$n = 10, \quad \beta = 18.2\%$$
$$n = \infty, \quad \beta = 20\%.$$

The above analysis has been made with respect to the shunting resistance provided by the terminal assembly plate, but exactly the same effect will be obtained if any shunting resistance is present on the testing apparatus used for the work. This indicates the importance of designing commercial testing apparatus for condenser testing so that shunt resistances of low value are eliminated.

The writer records his thanks to Standard Telephones and Cables Ltd. for permission to publish this paper.

Standard Telephones and Cables, Ltd.,
Connaught House, Aldwych, W.C.2, London.

Absolute Sulphuric Acid.—DARWIN HARRIS (*Chemist-Analyst*, 1932, **21** no. 4, 11) prepares absolute (100 per cent.) sulphuric acid by cooling concentrated sulphuric acid to a temperature of − 10° C. or lower; crystals of the absolute acid slowly separate. After some time, the liquid is poured off; and the crystals are drained quickly, and then placed in a dry bottle. If the original acid is not sufficiently concentrated, the product obtained is sulphuric acid monohydrate, $H_2SO_4.H_2O$, which melts at 8.53° C., while the absolute acid melts at 10.46° C.

J. S. H.

Preservation of Thiocyanate Solutions.—Standard solutions of thiocyanates (sulphocyanates, sulphocyanides) are used extensively in volumetric analysis. They tend to change their titer as the result of infection by, and subsequent growth of molds. JOSEPH GREENSPAN (*Jour. Am. Chem. Soc.*, 1932, **54**, 2850) states that the addition of one drop of toluene for each 100 cc. of approximately fiftieth normal solution of thiocyanate prevents mold growth and change in titer for a period of at least three weeks.

J. S. H.

Germanium Tetrachloride.—ELTON R. ALLISON AND JOHN H. MÜLLER (*Jour. Am. Chem. Soc.*, 1932, **54**, 2833–2840) find that germanium tetrachloride is practically insoluble in concentrated hydrochloric acid. Arsenious chloride can be removed completely from germanium tetrachloride by extraction with concentrated hydrochloric acid. The chlorides of antimony, tin, and titanium may be removed from germanium tetrachloride by a single extraction with concentrated hydrochloric acid.

J. S. H.

MEDAL DAY MEETING.

The annual Medal Day Meeting of The Franklin Institute was held in the Hall of the Institute at three-thirty o'clock on the afternoon of Wednesday, May eighteenth.

This meeting, which was also the regular monthly meeting, was called to order by the President, Mr. Nathan Hayward.

Upon motion, the minutes of the preceding monthly meeting were approved as printed in full in the JOURNAL OF THE FRANKLIN INSTITUTE.

The presentation of Honorary Memberships and Medals was next taken up. All the awards recommended by the Committee on Science and the Arts during the present Institute year were given at this time.

AWARD OF CERTIFICATE OF HONORARY MEMBERSHIP.

To Dr. George A. Hoadley, Swarthmore, Pennsylvania. Dr. Howard McClenahan, sponsor.

The President called upon Dr. McClenahan.

Dr. McClenahan: "Mr. President, it is a very peculiar satisfaction to present to you, for induction into Honorary Membership, Dr. George A. Hoadley, 'in recognition of a lifework devoted successfully to the advancement of physics: as an inspiring teacher, a stimulating author, and the effective executive officer of the Committee on Science and the Arts of The Franklin Institute.'"

The President presented the Certificate as follows: "In grateful appreciation of your devotion to The Franklin Institute, I present you with this Certificate of Honorary Membership. It gives us all much pleasure to pay honor to you. And may I add my own expression of admiration and affection."

Dr. Hoadley expressed his deep appreciation of the award of this honor to him.

AWARD OF THE CERTIFICATE OF MERIT.

To Mr. Thomas Randolph Harrison, B.S. in E.E. The Brown Instrument Company, Philadelphia, Pennsylvania. Mr. E. L. Clark, sponsor.

The President called upon Mr. Clark.

Mr. Clark: "Mr. President, I present Mr. Thomas Randolph Harrison, to receive a Certificate of Merit, 'in consideration of the improvements made in an electric flow meter, containing several conveniences which render it a highly flexible and adaptable instrument.'"

The President presented the Certificate as follows: "Mr. Harrison, in accordance with this recommendation and by my authority as President of The Franklin Institute, I present to you this Certificate of Merit."

Mr. Harrison expressed his appreciation of this presentation.

AWARD OF THE LONGSTRETH MEDAL.

To Mr. Josua Gabriel Paulin, System Paulin Aktiebolag, Stockholm, Sweden. Dr. J. S. Hepburn, sponsor.

The President called upon Dr. Hepburn.

Dr. Hepburn: "Mr. President, I have the honor to present to you, upon the recommendation of the Committee on Science and the Arts, Mr. Josua Gabriel Paulin, in absentia, as the recipient of the Edward Longstreth Medal, 'in consideration of the invention of a form of barometer with which difference in elevation can be quickly determined.' Mr. Paulin is represented by the Vice Consul for Sweden in Philadelphia, Mr. Hogeland."

The President presented the Medal as follows: "Mr. Consul, it is a great honor to hand to you the Longstreth Medal, given by The Franklin Institute to Mr. Josua Gabriel Paulin. We ask you to forward it to him."

In accepting the award the Consul replied: "I shall take great pleasure in forwarding this to him and wish to extend his thanks for this honor."

AWARD OF WETHERILL MEDALS.

To Mr. Halvor Olsen Hem, Toledo Scale Manufacturing Company, Toledo, Ohio. Mr. Warren P. Valentine, sponsor.

The President called upon Mr. Valentine.

Mr. Valentine: "Mr. President, upon the recommendation of the Committee on Science and the Arts, a John Price Wetherill Medal has been awarded to Mr. Halvor Olsen Hem, of the Toledo Scale Manufacturing Company, 'in consideration of the ingenuity shown in perfecting scales of the pendulum type, improving their accuracy, reliability and sensitiveness, and for his application of these scales to specific purposes.' I present Mr. Hem to you."

The President: "In the name of The Franklin Institute, upon the recommendation of its Committee on Science and the Arts, I present to you the John Price Wetherill Medal."

Mr. Hem expressed his thanks for this award.

To Monroe Calculating Machine Company, Inc., Orange, New Jersey. Mr. J. C. Trautwine, 3d, sponsor.

The President called upon Mr. Trautwine.

Mr. Trautwine: "Mr. President, in accordance with the findings of the Committee on Science and the Arts, the Board of Managers of The Franklin Institute has voted to award to the Monroe Calculating Machine Company a Wetherill Medal, 'in consideration of the excellent design and construction of the improvements which have been made by the Monroe Calculating Machine Company on the Baldwin Machine patented in 1874, which improvements are embodied in the modern Monroe Calculating Machine.' I present the Company's representative, Mr. E. F. Britten, Jr."

The President: "Mr. Britten, upon the recommendation of the Committee on Science and the Arts as just given, I have the honor to present to you, the representative of the Monroe Calculating Machine Company, a John Price Wetherill Medal."

Mr. Britten responded: "On behalf of the Monroe Calculating Machine Company, I wish to thank you for the honor which you have bestowed upon that Company."

To Messrs. Baltzar Carl von Platen and Carl Georg Munters, Platen-Munters Refrigerating System, Stockholm, Sweden. Mr. J. Logan Fitts, sponsor.

The President called upon Mr. Fitts.

Mr. Fitts: "Mr. President, the Committee on Science and the Arts recommends that a John Price Wetherill Medal be awarded to Messrs. Baltzar C. von Platen and Carl G. Munters, of Stockholm, Sweden, 'in consideration of their pioneer work and ingenuity in evolving an absorption type of apparatus for refrigeration by using an inert gas to equalize the pressures required in the system.' These gentlemen are represented by the Swedish Consul in Philadelphia. I present Mr. Hogeland."

The President: "Mr. Consul, it again gives me pleasure to present an award to you. I hand you this John Price Wetherill Medal, which I would ask you to forward to Messrs. von Platen and Munters."

Mr. Hogeland accepted the award on behalf of the gentlemen named.

To Dr. Frank Wenner, Bureau of Standards, Washington, D. C., Dr. W. R. Wright, sponsor.

The President called upon Dr. Wright.

Dr. Wright: "Mr. President, I have much pleasure in presenting to you Dr. Frank Wenner, of the Bureau of Standards of Washington, as the recipient of a John Price Wetherill Medal, 'in consideration of his ingenious design of a recording teleseismograph of superior performance.'"

The President: "Dr. Wenner, upon the recommendation of the Committee on Science and the Arts, as just given, I, as President of The Franklin Institute, have the honor to present to you this John Price Wetherill Medal."

In response Dr. Wenner said: "I assure you, I appreciate this honor."

AWARD OF THE LEVY MEDAL.

To Dr. Wayne Buckles Nottingham, Assistant Professor of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts. Dr. T. K. Cleveland, sponsor.

The President called upon Dr. Cleveland.

Dr. Cleveland: "Mr. President, the Committee on Science and the Arts, after lengthy deliberation, recommends the award of the Louis Edward Levy Gold Medal to Dr. Wayne Buckles Nottingham, for his paper in the March, 1931, issue of the

JOURNAL OF THE FRANKLIN INSTITUTE, entitled, 'Characteristics of Small Grid-Controlled Hot Cathode Mercury Arcs or Thyratrons.' I have much pleasure in presenting him to you."

The President presented the Medal as follows: "Dr. Nottingham, in recognition of the high quality of the article published in the JOURNAL OF THE FRANKLIN INSTITUTE which has just been described, The Franklin Institute has awarded to you the Louis Edward Levy Gold Medal. Due to your former connection with the Bartol Laboratory, we all share with you this honor."

In accepting the Medal, Dr. Nottingham said: "I want to thank you for this great honor. I am glad also to acknowledge the fact that I am, in a sense a son of The Franklin Institute."

AWARD OF THE CLARK MEDAL.

To Mr. Philip Thornton Dashiell, Ph.B., United Gas Improvement Company, Philadelphia, Pennsylvania. Mr. Theobald F. Clark, sponsor.

The President called upon Mr. Clark.

Mr. Clark: "Mr. President, it is my privilege to present to you Mr. Philip Thornton Dashiell, of the United Gas Improvement Company, who has been awarded the Walton Clark Gold Medal by the Board of Managers of The Franklin Institute, 'in recognition of his outstanding contributions to the carburetted water gas industry as embodied in his fuel oil carburetion process.'"

The President presented the Medal as follows: "As President of The Franklin Institute, I have the honor to present to you the Walton Clark Medal, in giving which the Institute honors both you and its former president, Dr. Clark, who is loved and honored by you as well as by us."

Mr. Dashiell expressed his thanks for the honor.

AWARD OF THE POTTS MEDAL.

To professor George Paget Thomson, F.R.S., Professor of Physics, Imperial College of Science and Technology, London, England. Dr. Frederic Palmer, sponsor.

The President called upon Dr. Palmer.

Dr. Palmer: "Mr. President, I have the honor to introduce, in absentia, Professor George Paget Thomson, Professor of Physics, Imperial College of Science, London, England, who has been awarded the Howard N. Potts Gold Medal, 'In consideration of his brilliant experimental demonstration of the wave properties possessed by high speed electrons.' I present the British Consul General, Mr. Watson, who will receive the Medal for Professor Thomson."

In presenting the Medal, the President said: "Mr. Consul General, it is a great honor to present to you the Potts Medal, given upon recommendation of our Committee on Science and the Arts, in recognition of the work of Professor George Paget Thomson, the distinguished son of a distinguished father. Will you be kind enough to forward this Medal to him?"

The Consul General made the following acceptance speech: "Mr. President, I am in receipt of a letter from George P. Thomson, in which he asks me, if occasion arises, to express his extreme gratitude to the Institute for the honor that it has paid to him by this award. If I may add a tribute to the unerring judgment of the Committee of The Franklin Institute in selecting men whom they consider worthy of high honor, which honors they have bestowed on someone or other year after year, I wish to state that I think they are very wise in selecting men who belong to the same alma mater as I do."

The Secretary of the Institute, Dr. McClenahan, here remarked: "Mr. President, may I say that our distinguished representative of the British Government has come to regard a request from us to represent someone of his countryman as an annual affair. He now 'counts that year lost whose low descending sun finds no gold or silver medal from The Franklin Institute won!'"

AWARD OF CRESSON MEDALS.

To Dr. Percy Williams Bridgman, Professor of Physics, Harvard University, Cambridge, Massachusetts. Dr. T. D. Cope, sponsor.

The President called upon Dr. Cope.

Dr. Cope: "Mr. President, upon the recommendation of the Committee on Science and the Arts, it is my pleasure to

sponsor the award of the Elliott Cresson Gold Medal to Dr. Percy Williams Bridgman, Professor of Physics, Harvard University, 'in consideration of his fundamental contributions to the technique of high pressure experimentation and of the vastly extended range of pressures which he has made available in the laboratory and of the wealth of information about properties of matter at high pressures which his researches have contributed.' I present Dr. Bridgman."

The President presented the Medal as follows: "Dr. Bridgman, in the name of The Franklin Institute, on recommendation of its Committee on Science and the Arts, and in recognition of your work in high pressure experimentation, by authority vested in me as President of the Institute, I award you the Elliott Cresson Medal. I wish to add, regarding the statement which Mr. Watson, the British Consul General, has just made, that there is a Cambridge in the United States and that an alumnus from a great institution there, with which you, Sir, are connected, now shakes your hand."

Dr. Bridgman: "Thank you, Mr. Hayward."

To Dr. Charles LeGeyt Fortescue, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pennsylvania. Mr. W. C. Wagner, sponsor.

The President called upon Mr. Wagner.

Mr. Wagner: "Mr. President, may I present to you Dr. Charles LeGeyt Fortescue, of the Westinghouse Electric and Manufacturing Company in Pittsburgh, for the award of the Elliott Cresson Gold Medal, 'because of his development of the Method of Symmetrical Coördinates Applied to the Solution of Polyphase Networks.' Dr. Fortescue."

The President: "Dr. Fortescue, it is my honor to hand to you the Cresson Medal which has been awarded to you by The Franklin Institute, in recognition of your contributions to the science of electrical engineering."

In accepting the Medal, Dr. Fortescue said: "Mr. President, I appreciate very greatly the honor which The Franklin Institute has conferred upon me."

To Dr. John Boswell Whitehead, Dean, School of Engineering, Johns Hopkins University, Baltimore, Maryland. Mr. C. W. Bates, sponsor.

The President called upon Mr. Bates.

Mr. Bates: "Mr. President, I have the honor to present to you Dr. John Boswell Whitehead, Dean of the School of Engineering, Johns Hopkins University, who, by action of the Board of Managers of The Franklin Institute, has been awarded the Elliott Cresson Gold Medal, 'in consideration of his many original investigations of dielectric behavior and allied subjects.' I present Dean Whitehead."

The President: "In the name of The Franklin Institute, by the power vested in me as President, I have much pleasure in presenting to you, Dean Whitehead, in recognition of your original investigations of dielectric behavior, the Elliott Cresson Medal."

Dean Whitehead expressed his hearty thanks for the presentation.

AWARD OF FRANKLIN MEDALS.

To Dr. Ambrose Swasey, D.Eng., Sc.D., LL.D., Warner-Swasey Company, Cleveland, Ohio. Dr. James Barnes, sponsor.

The President called upon Dr. Barnes.

Dr. Barnes: "Mr. President, I have the honor to present to you, upon recommendation of the Committee on Science and the Arts, Dr. Ambrose Swasey, as the recipient of a Franklin Medal, 'in recognition of his development of methods and his invention of appliances for making machines, tools, and instruments of the highest precision, of the design and construction of the mountings of many of the world's largest telescopes, and of his scientific vision in the establishment of the Engineering Foundation for the promotion of research and its application in the various fields of engineering.'

"It is our custom to briefly outline the work for which this award is recommended: Dr. Swasey has been granted twenty-two patents. He invented an epicycloidal milling machine for producing theoretical curves by means of which cutters for gear-teeth are made. He developed a great dividing engine which cut scales of high accuracy. He invented a gear cutting machine in which rotating cutters are employed. The cutting portions represented a cross section of the rack into which the teeth of the desired gear meshed. Such cutters

were fed across the face of the gear blank and made the curves in which the teeth of the rack fit.

"The firm of Warner and Swasey designed and constructed the beautiful mountings for four large telescopes in the United States, for one in Canada and for one in the Argentine. Dr. Swasey conceived and planned the Engineering Foundation, the purpose of which was the advancement of the knowledge and the interests of engineering science in all possible ways. He endowed this foundation generously and through its agency highly valuable contributions to engineering knowledge have been obtained. Dr. Swasey."

The President then presented the Medal, the Certificate and the Certificate of Honorary Membership, as follows: "Dr. Swasey, in recognition of your invention of instruments of great precision, for your production of mountings of many of the world's great telescopes, and for your establishment of the great Engineering Foundation, The Franklin Institute awards to you the Franklin Medal, which is the highest award in its power to confer. By authority vested in me as President of the Institute, I have the honor to present to you, Sir, this Medal and with it this Certificate of Honorary Membership in the Institute."

Dr. Swasey responded: "Mr. President, more than I can express to you, I appreciate this high honor, and I am especially pleased to join the honor roll of this wonderful institution. I am very happy to be able to be here to receive these honors. Thank you."

The President assured Dr. Swasey that he was no more glad to be here than we were to have him.

To Geheimrat Professor Philipp Lenard, Ph.D., Director, Radiological Institute, University of Heidelberg, Heidelberg, Germany. Represented by the German Consul General in New York, Dr. O. C. Kiep. Dr. James Barnes, sponsor.

The President called upon Dr. Barnes.

Dr. Barnes: "Mr. President, your Committee on Science and the Arts recommends that a Franklin Medal be awarded to Dr. Philipp Lenard, 'in recognition of a lifework devoted to fruitful research in physics, in the course of which he added greatly to scientific knowledge and especially showed that it was possible for cathode rays to exist outside the generating

tube and determined the effects produced by such rays; he also discovered the electronic nature of the emission from surfaces upon which ultraviolet light falls, as well as the basic laws of photoelectricity.'

"Dr. Lenard has published almost a hundred articles in the learned journals and six books. He was the first to devise a method by which cathode rays may be obtained outside the generating tube. This he did by closing the end of the generating tubes opposite the cathode with windows of extremely thin metal foil. These external cathode rays are known as Lenard Rays.

"Dr. Lenard recognized the true cause of the photoelectric effect for he showed that many surfaces illuminated by ultraviolet light emitted negative charges with an e/m of the same magnitude as that possessed by electrons but with a very much smaller velocity than that of ordinary cathode rays. He also discovered the two fundamental laws of photoelectricity.

"Mr. President, it is a source of keen regret that Dr. Lenard is unable to be here today. We are, however, highly appreciative of the courtesy of the German Consul General in New York in coming to us to receive, on behalf of Dr. Lenard, this medal. I have, Sir, the honor of presenting to you Dr. Kiep."

The President then presented the Medal, the Certificate and the Certificate of Honorary Membership as follows: "Mr. Consul General, The Franklin Institute has much pleasure in honoring your countryman, Professor Dr. Philipp Lenard, by presenting to him its highest award, in recognition of a life work devoted to fruitful research in physics. As President of The Franklin Institute, it is my privilege to hand to you this Franklin Medal, together with a Certificate of Honorary Membership, which I would ask you to forward to Dr. Lenard, in our name; and may I thank you for your courtesy in coming to participate in our functions."

In accepting the honors for Dr. Lenard, Dr. Kiep, the German Consul General in New York, said: "Mr. President, in listening to the wonderful record of the distinguished scientist I have the honor to represent here, I have been trying to grasp a small part of the technical details of the work he

has accomplished, and for which you are honoring him. But also, in associating myself with my colleague from Great Britain in becoming, I might say, a regular customer, I find myself farther away than ever from grasping the height and scope of intricacy of the sciences which you here cultivate and honor throughout the world. Perhaps, it is because I belong to that profession which undertakes to handle the affairs of all people, that it is hard for me to understand a single point. I wish to assure you, Mr. President, that the recipient of this medal is deeply conscious of the high honor and distinction you have conferred upon him. He asks me to express to you his sincere thanks and his appreciation of what you have done, which will be an impulse to him to pursue further his studies for the enlightenment, not only of his own country, but for science throughout the world. I thank you for this great honor. I am happy that my representing him will be restricted only to the receiving of the medal and that his achievements will be presented in his own words here."

After the presentation of the Medals, two papers were read which had been prepared by the Franklin Medalists of the day. The first was written by Dr. Lenard but in his absence was presented by one of his colleagues in this country, Dr. C. B. Thwing; the second was prepared and read by Dr. Swasey.

In introducing Dr. Thwing, Mr. Hayward said: "As the Consul General has just said, the recipient of the Franklin Medal, Dr. Lenard, has written a paper which will now be read by a former student of his. I have the honor to present to you Dr. Thwing."

Dr. Thwing: "It was my good fortune in 1893 to be the last pupil of Hertz and to hear the first course of lectures given by Lenard. Lenard was exceptional in many ways. He is a large, active man, very full of energy. Nothing could tire him, but he was one of the most bashful, modest men I have ever seen. During his course of lectures he had occasion, in touching upon the various points that concerned his lecture, to take us out on a balcony to show us an instrument for measuring the electrical potential of the air. In this less formal situation (conversation in a German lecture room was quite un-

heard of) one of the students said to me 'What a delightful course of lectures and how very very interesting!' And I agreed with him.

"Lenard's room was down in a terrible old basement which was the death of Hertz—and nearly the death of me—but did not seem to hurt Lenard. When I went to my room after the lecture just mentioned, he was very much excited and asked, 'What did that young fellow say? Was he criticizing my lecture?' I replied, 'O! No. On the contrary, he was praising it!' Thereupon he quieted down but said to me, 'Well, a young man might say that, but I don't see how you can find anything of interest in my work.' I then told him of the pleasure I had in listening to his lectures. That brief interview was the beginning of a regular friendship between us and we corresponded for years.

"About eight years after that I desired to name my second son for him. I wrote him a letter requesting his permission. He was greatly pleased and cabled me, "Gratuliere herzlich. Stimme freudig zu."

"It was my grief that the war came and my son was fighting in France. I could not write to Dr. Lenard and tell him that his namesake was fighting against his country. Our correspondence ended. I am now going to write to him in the hope that this cherished friendship may be renewed. (Dr. Thwing then read a translation of a paper which Dr. Lenard had submitted in German. The paper appears in full in this issue of the JOURNAL, page 257.)

After Dr. Thwing had read the paper, the President said: "Thank you Dr. Thwing. I hope, Mr. Consul General, that when you write to Professor Lenard, you will tell him how much we enjoyed his paper."

In introducing Dr. Swasey, the President remarked: "The other recipient of the Franklin Medal, Dr. Swasey, has been good enough to write a paper which he is now going to give us the pleasure of hearing. Dr. Swasey."

Dr. Swasey then delivered, in a very delightful manner, an excellent paper on his work and the enjoyment he had found in it. This paper appears in full on page 265.

After thanking Dr. Swasey for his very interesting paper, the President declared the meeting adjourned.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A NEW INDUSTRY—MANUFACTURE OF SOUND ABSORBING MATERIALS.

In the bureau's files there is to be found the record of the development of a new industry. This of itself is noteworthy, but additional interest attaches to this case from the fact that fully three-quarters of this development has occurred during the business depression of the last three years. Reference is made to the manufacture of sound absorbing materials for use in correcting the acoustic quality of auditoriums.

Though the underlying principles of architectural acoustics have been known for nearly 40 years the subject attracted but little attention from those who should have been interested until the introduction of talking pictures. It was then found that many theatres which had been built for silent pictures were acoustically almost useless. This discovery stimulated the study of means for correcting the difficulty and directed attention to such sound absorbing materials as were then available.

These materials were limited in number, and some of them were serious fire risks. Development of new materials to meet the demand brought requests for service in the measurement of their sound absorption.

In 1928 the facilities for this work were limited to two laboratories, both in the State of Illinois. In the fall of 1928 the Bureau of Standards completed a reverberation room for making such tests and placed it in service. During the remainder of that year its facilities were used by two manufacturers.

In 1929 seven different firms sent material for measurement, and this number was increased to 18 in 1930 and 23 in 1931, in which year the total number of samples measured was 97. For the first half of 1932 the demand for service of this character has been considerably in excess of the 1931 rate.

* Communicated by the Director.

Another measure of the extent to which the bureau has been connected with this new manufacturing development is found in the increasing correspondence on the subject. So frequent became letters of inquiry regarding different acoustic materials that early in 1930 it became necessary to issue a Letter Circular on the subject. The first edition of this circular in March 1930 listed 11 materials which the bureau had measured up to that time. Seven editions of this Letter Circular have been called for, each edition listing an increasing number of materials. The latest edition, of April 1932, lists 37 different materials, with several varieties of each, totaling 87.

In addition to furnishing this service, the bureau has been called upon by architects for advice regarding the preliminary calculation of the acoustic quality of a proposed auditorium. It has become an established rule of the Government architects to submit to the bureau all plans for new Federal courtrooms throughout the country for suggestion and criticism in this respect.

The bureau has also done its share toward developing improved methods and instruments for making sound absorption measurements. The following publications, obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at the prices named, give a description of the bureau's work along these lines.

Heyl, Paul R., Architectural Acoustics, B. S. Circular No. 396, 1931. (C396, 5¢.)

Eckhardt, E. A., and Chrisler, V. L., "Transmission and Absorption of Sound by Some Building Materials," *B. S. Sci. Papers*, **21**, 37, 1926–27. (S526, 15¢.)

Heyl, Paul R., Chrisler, V. L., and Snyder, W. F., "The Absorption of Sound at Oblique Angles of Incidence," *B. S. Jour. Research*, **4**, 289, 1930. (RP149, 5¢.)

Chrisler, V. L., and Snyder, W. F., "The Measurement of Sound Absorption," *B. S. Jour. Research*, **5**, 957, 1930. (RP242, 10¢.)

INFLUENCE OF ATMOSPHERIC CONDITIONS ON SOUND ABSORPTION.

During the past two years a study has been made at the bureau of the sound absorbing properties of air under various conditions. As a result of this study some curious facts have been found. When the air is very dry sound is absorbed much more readily than when the air is full of moisture. Also when the temperature is high sound is absorbed better than when it is cold. This increased absorption is most pronounced for sounds of high pitch. The conditions then for maximum absorption are those prevailing on a hot dry day. Under these conditions it has been found that sound can not be heard as far on a cool, damp day.

This problem is of considerable interest in broadcasting studios where an attempt is made to keep the absorption constant. This can be done by the use of an air conditioning system, and in many studios such a control has been installed.

It has also been found that the rate of decay of sound in a room does not follow exactly the uniform law that has hitherto been assumed, but that the rate of decay is influenced by the area of absorbing material present and its distribution.

Research Paper No. 465, in the August number of the *Bureau of Standards Journal of Research*, will give a complete account of this work.

VACUUM TUBE AMPLIFIER FOR FEEBLE PULSES.

In recent years various experimenters have attempted to amplify and record the primary ionization produced when a single corpuscular ray, such as a high speed electron or alpha-ray, passes through a shallow ionization chamber. Wynn-Williams and Ward working in England and Leprince-Ringuet in France have described successful amplifiers of this kind. These amplifiers, however, use foreign tubes and the details of their circuits are of little value to those who must use radio tubes made in this country. In Research Paper No. 461, which will appear in the August number of the *Bureau of Standards Journal of Research*, a description is given of an amplifier using the commercial a.c. screen grid amplifier tubes and a pentode, combined with a special electrometer tube which

can be made in any laboratory having facilities for glass blowing. This amplifier, when used with an improved ionization chamber which is described, will give current pulses of the order of fifty milliamperes for a single alpha particle. This means that the original current produced when the alpha particle passes through the ionization chamber has been amplified to approximately a thousand million times its original value. This arrangement is of great assistance in studying atomic disintegration and is essentially the same as that used by Dr. Chadwick of Cambridge, England, in the recently reported discovery of the "neutron."

LEGIBILITY OF BAROGRAPH TRACES.

Tests were recently completed at the bureau to determine the legibility of barograph traces made upon charts sprayed with a lamp black solution when differently shaped scribers were used. Tests were also made to determine the best kind of paper to use for the chart. It was found that a trace made by a sharp or pin-pointed scriber was superior to those made by the other two types of scribers in common use, namely, the fairly blunt point obtained by shaping the end of the barograph arm, and the triangular cup type which is used necessarily when the traces are made in ink upon white paper. The pin-pointed scriber is commonly made by soldering a straight pin to the end of the arm of the barograph, bending it in a suitable manner, and sharpening it upon a stone. Three types of paper were tested: A thin typewriting paper, bonded letterhead paper, and a heavy paper commonly called "statement paper." The statement paper was the most satisfactory, as it was the easiest to handle and gave the best trace.

LATHE ATTACHMENT FOR TURNING APPROXIMATELY SPHERICAL SURFACES.

When constructing machinery or tools it is often necessary to produce a small portion of a spherical surface of which the radius of curvature is large. For example, in the production of optical surfaces on lenses, grinding tools are often from 5 to 20 inches in diameter and faced by surfaces of which the radii

of curvature may be as great as 10 or 20 feet. For more moderate values of the radius of curvature such surfaces are easily produced on a lathe by a tool carried on the end of a radius rod but for the larger values this method is inconvenient or impracticable. There is a method by which such surfaces can be milled, but this requires a special machine of heavy and very expensive construction which is not ordinarily available. In a method more commonly used the surface is produced on a lathe by a single-tooth tool guided by a carefully constructed template. With this method a separate template is necessary for each required radius and the method, therefore, is satisfactory only when a large number of surfaces having the same radius of curvature is desired.

A new attachment has now been constructed at the bureau for producing these curved surfaces. It is relatively inexpensive and is substituted for the compound slide rest on a lathe. A special linkage guides the tool in such a manner as to generate an approximately spherical surface. By a simple adjustment the linkage can be set to produce either a convex or a concave surface with any desired radius of curvature greater that a certain minimum value which is approximately 20 inches for the attachment which has been constructed. The approximation to a spherical surface becomes better as either the curvature or diameter of the surface is decreased. A surface of 8 inches in diameter with a radius of curvature of 40 inches is produced with a departure from a spherical surface which is less than 0.001 inch. If the radius of curvature is decreased to 20 inches and the diameter of the surface is 12 inches, the departure is approximately 0.01 inch. This last value is the maximum value for any surface lying within the working range of the instrument.

This development will be described in detail in Research Paper No. 467 in the August number of the *Bureau of Standards Journal of Research*.

SPECIFICATIONS FOR PHOTOGRAPHIC PAPER.

Specifications for photographic black-line paper and photographic negative paper, prepared by the photographic supplies committee of the Federal Specifications Board, have been

approved for use of the departments and independent establishments of the Government in the purchase of those commodities. The service requirements for the papers are rather severe because they must be strong to withstand frequent handling and have sufficient purity to last for many years without appreciable deterioration. The specifications are of special interest because the fiber requirements are based on information developed in the bureau's studies on the permanence of paper. The results obtained in these studies have indicated that ability of a paper to resist aging is dependent, as far as the character of the fibers is concerned, on their cellulosic purity. Consistent with this new criterion of quality, the specifications contain no reference to the kind of fiber stock, except a requirement in each case that it be free from unbleached or highly lignified fibers, such as ground wood fibers, which are known to be harmful.

The detail requirements include values for wet tensile strength sufficient to withstand handling when wet by immersion in developing solutions, and such values for alpha cellulose content and copper number as to insure sufficient purity of the cellulosic materials composing the papers. The alpha cellulose test is a measure of the unmodified cellulose present and the copper number test is a measure of the degraded cellulose or harmful substances. Permanent paper is characterized by high alpha cellulose content and low copper number.

Coöperative tests for one manufacturer indicated that the black-line and negative papers regularly furnished by him failed to meet the chemical purity requirements of the specifications. A paper stock of foreign manufacture was used in these papers, and it is of interest to note that this manufacturer by substituting a domestic paper stock has improved his products to such an extent that they now conform to the specifications in all respects.

INFLUENCE OF TEMPERATURE ON EVOLUTION OF HYDROGEN SULPHIDE FROM VULCANIZED RUBBER.

When raw rubber is heated with sulphur, it undergoes a marked change in properties and forms what is commonly known as vulcanized rubber. The amount of sulphur com-

bined with the rubber may range from a fraction of one per cent. to about 32 per cent. The products containing the lower percentages of sulphur are soft and occur in familiar articles such as automobile tires and many household rubber goods. The ordinary hard rubber is an example of a compound containing the higher percentages of sulphur.

Vulcanized rubber is used commercially in many articles, such as gaskets, steam hose, and brake lining, which are subjected to relatively high temperatures. When vulcanized rubber is heated, it gives rise to an unpleasant order which becomes more intense and more disagreeable the higher the temperature. The odor is due in large part to sulphur compounds which are derived from the sulphur that was used to vulcanize the rubber. This loss of sulphur is accompanied in general by deterioration in the electrical and mechanical properties of the rubber.

A study has been made at the bureau to ascertain the extent to which rubber of various compositions decomposes on heating. The purpose of the investigation was to determine to what temperature and for what length of time vulcanized rubber could be heated without producing a serious change in the composition. In this study, measurements were made of the principal product of decomposition, hydrogen sulphide. Below the temperature of boiling water the rate of decomposition was so slow that no significant portion of the sulphur content was lost. As the temperature was increased, however, the rate of evolution of hydrogen sulphide increased rapidly. Hard rubber, vulcanized with about one-third its weight of sulphur, lost hydrogen sulphide much more rapidly than did soft rubber vulcanized with only a fraction as much sulphur. After 24 hours' heating at 430° F., hard rubber lost about one-third of its sulphur content and changed to a brittle, translucent, reddish-brown material.

The results of this investigation afford fundamental data from which it is possible to determine how much a sample of rubber will decompose when the composition of the rubber and the time and temperature are given.

Measurements were not made on the change in strength, or other physical properties, although qualitative observations in this regard were recorded. For a complete account

of the work, Research Paper No. 464, which will be published in the *Bureau of Standards Journal of Research* for August, should be consulted.

CELLULAR SHEET-STEEL FLOORING.

The weights of floors in buildings are often greater than the loads which they support. Consequently engineers are interested in methods of reducing this dead load since any such reduction would permit economies in the frames and foundations.

There has recently been completed at the bureau a study of the behavior under transverse loading of a new light-weight cellular floor made from sheet steel. The floor consists of two corrugated sheets spot-welded together into a panel two feet wide and of lengths up to twelve feet. The weights of the specimens tested ranged from 8 to 16 lbs./ft.^{2} These panels have the additional advantage that electrical and plumbing lines can be placed in the ducts formed by the longitudinal cells.

In the tests, which will be reported in Research Paper No. 463 in the August number of the *Bureau of Standards Journal of Research*, the panels were loaded at the quarter-points and the deflections and strains measured at mid-span. It was found that the methods customarily used by engineers when designing steel structures were satisfactory for predicting the elastic behavior of the floor panels. These panels will carry uniformly distributed loads of from 200 to 940 lbs./ft.^{2} on a ten-foot span before they begin to depart from elastic behavior. The concentrated reactions at the ends of the panels and the concentrated loads at the quarter-points did not greatly affect the strength or other properties of the panels. The maximum load carried by the specimens was, in all cases, considerably higher than the elastic limit of the panels. This fact and the relatively great deflection under maximum load provides an ample margin of safety against sudden failure under excessive loads or under impact.

In the course of the investigation the tensile properties of the sheet steel and the shearing strength of the spot welds were also determined. A new type of specimen was devised for making tests of the welds.

REVISED METRIC PAMPHLET.

All those interested in the metric system of weights and measures will welcome the revised (third edition) of "The International Metric System of Weights and Measures," which has just been released.

This pamphlet gives a brief history of the system, including the establishment of the International Bureau of Weights and Measures at Paris, by 17 nations, including the United States. This is followed by a revised list of the various countries which now support this bureau. A complete synopsis of the system follows, with explanations of the methods of deriving the various units.

Quotations are given from the laws of the United States, defining the status of the metric system in this country.

Lastly, tables are included giving a comparison of the metric and customary units of weight and measure.

Several changes have been made in the pamphlet since the second edition which was published in 1922. These include a revision of the list of nations supporting the International Bureau of Weights and Measures, certain changes in the text which make for greater clearness, revision in legends accompanying illustrations, discarding of obsolete material and insertion of new data, and certain revisions in the table of equivalents.

Copies of this publication (Bureau of Standards Miscellaneous Publication No. 135) may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

Peroxide-free Ether.—F. W. NITARDY AND E. C. BILLHEIMER (*Jour. Am. Pharmaceutical Asso.*, 1932, **21**, 112–113) report that peroxide-free anesthetic ether marketed in copper-lined tin containers remains free from peroxide and other decomposition products even when kept at elevated temperatures for long periods of time. The same ether develops peroxide when stored in other types of containers. The metallic copper combines with any oxygen which is present, to form cuprous oxide; this, in turn, reacts with both the peroxide (if present) and its immediate precursor, which accompanies the ether in its distillation; acetic acid probably is formed. Thus formation of peroxide in the stored ether is prevented.

J. S. H.

Ginger Paralysis.—MAURICE I. SMITH AND E. ELVOVE (*Public Health Reports*, 1931, **46**, 1227–1235) show that so-called ginger paralysis is due, not to the ingestion of fluid extract of ginger, but to the presence of tri orthocresol orthophosphate as an adulterant of the fluid extract. In man, the paralysis develops several weeks after ingestion of the adulterated fluid extract. The toxic adulterant may be concentrated, and then produces the typical paralysis when administered to rabbits or hens, more rapidly in the former.

J. S. H.

American Glycerol.—JOSEPH W. ENGLAND (*Am. J. Pharmacy*, 1932, **104**, 489–494) states that the first glycerol made in the United States was the sample prepared in 1846 by Robert Shoemaker of Philadelphia for Prof. Wallace Procter, Jr., of the Philadelphia College of Pharmacy, for exhibition to his classes. This sample, prepared from water in which lead plaster had been kneaded and cooled, is still in the possession of the Philadelphia College of Pharmacy and Science. In 1848, Shoemaker placed glycerol on the market; it sold for $4.00 per pound; and the first sale was one-quarter pound. The entire sales of 1848 amounted to 15 pounds, those of 1849 to 200 pounds. The price per pound was $3.00 in 1849, and $2.70 to $2.75 toward the end of 1850. In 1879 glycerol sold for 18 cents per pound; today the price in large quantities is about 11 cents per pound.

J. S. H.

THE FRANKLIN INSTITUTE.

LIBRARY NOTES.

RECENT ADDITIONS.

Allen's Commercial Organic Analysis. Volume 9. 1932.

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American Society of Refrigerating Engineers. Refrigerating Data Book and Catalog. First edition, 1932–1933.

BAKER, ERNEST A. Caving. Episodes of Underground Exploration. 1932.

BEAVIS, GERALD. The Book of the Microscope. 1932.

Biblia Das ist die ganze Göttliche Heilige Schrift Alten und Neuen Testaments, nach der Deutschen Uebersetzung Dr. Martin Luthers. Dritte Auflage. Germantown, Saur. 1776.

COKER, E. G., AND L. N G. FILON. A Treatise on Photo-Elasticity. 1931.

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HERMELIN, SAMUEL GUSTAF. Report about the Mines in the United States of America, 1783. Translated from the Swedish with Introduction and Notes by Amandus Johnson. 1931.

HOPKINS, ALFRED. Prisons and Prison Building. 1930.

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JONES STANHOPE BAYNE-. Man and Microbes. 1932.

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MILLER, WALTER VON. Oskar von Miller nach eigenen Aufzeichungen, Reden und Briefen. 1932.

MEASE, JAMES. The Picture of Philadelphia. 1811.

MENGE, EDWARD J. V. K. Jobs for the College Graduate in Science. 1932.

Mitchell's National Map of the American Republic or United States of North America. 1843.

MOTZ, WILLIAM H. Principles of Refrigeration. Third edition. 1932.

MYERS, LOUIS GUERINEAU. Some Notes on American Pewterers. 1926.

OLMSTED, DENISON. Introduction to Astronomy. Revised edition. 1860. Volume contains also Introduction to Practical Astronomy, Designed as a Supplement to Olmsted's Astronomy by Ebenezer Porter Mason. 1858.

Organic Syntheses: an Annual Publication of Satisfactory Methods for the Preparaton of Organic Chemicals. Volume XII. 1932.

SCHOYER, SOLOMON, Publisher. Map of the United States. 1826.

Sweet's Architectural Catalogues for the year 1932. In four volumes. 1932.
Sweet's Engineering Catalogues for the year 1932.
ULRICH, CAROLYN F., Editor. Periodicals Directory: a Classified Guide to a Selected List of Current Periodicals, Foreign and Domestic. 1932.
WIBORG, FRANK B. Printing Ink: a History with a Treatise on Modern Methods of Manufacture and Use. 1926.
WRIGHT, L. K. Official Refrigeration Manual. 1931.
Zeitschrift für anorganische und allgemeine Chemie. Generalregister. der Bände 151–200 (1926–1931). 1932.

BOOK REVIEWS.

ALLEN'S COMMERCIAL ORGANIC ANALYSIS. Fifth Edition, Revised and Partly Rewritten. Edited by C. Ainsworth Mitchell. Volume IX, 617 pages, illustrations, 16 x 24 cms. Philadelphia, P. Blakiston's Son & Co., Inc. Copyright 1932.

This volume is devoted to plant proteins; milk, its proteins and its products; and meat and its products. The section on plant proteins by D. Jordan Lloyd describes those found in cereals, flour, leguminous seeds, nuts, oil-seeds, roots, tubers, fruits, and vegetables, as well as the food value of proteins, and the separation of their constituent amino acids. The proteins of milk receive attention in a section by G. D. Elsdon. John Golding contributes the section devoted to milk of cows and other animals, including analytic procedures, interpretation of analytic results, and detection of artificial colors, preservatives, adulteration, and pollution. The section on milk products by E. R. Bolton considers cream, skim milk, buttermilk, whey, condensed milk, fermented milk, dried milk, cheese, and such products as humanised (modified), peptonised, and irradiated milks. Approximately two-thirds of the volume is devoted to a monograph by C. Robert Moulton on meat and meat products, including their composition, analysis, decomposition, preservation, cold storage, and derivatives such as sausage and meat extract. Poultry, eggs, and fish also receive attention.

J. S. H.

JOBS FOR THE COLLEGE GRADUATE IN SCIENCE, by Edward J. v. K. Menge, Ph.D., Sc.D., 175 pages, 14 x 20.5 cms. New York, The Bruce Publishing Company, 1932. Price $2.00.

No question presses more than the absorption into life of the perennial edition of educated youth. Certain educators propose the "stretch-out" system, extending the four-year college course to six years. This would postpone the problem to the sixth year. Dr. Menge meets young men and young women who have trained in science with his very suggestive book which describes just where jobs can be had. It is like the vision of an oasis in a desert land.

For example the trained astronomer will find the Federal Government employs a total of thirty-seven astronomers, with various observatories using a few more men of this science. Similarly the geologist can read of the places where his or her services may be in demand. The qualifications required, the associations existing, the books to consult are listed for those skilled in mathe-

matics, physics, chemistry, dentistry, pharmacy and the treatment of animals. Engineers of all sorts and those trained in the biological sciences are also served with timely and useful information bearing upon the all important problem of where to get a job.

This book is one of the most practical answers to unemployment that it has been my good fortune to meet. It is well worth the price of $2.00 and if taken from the shelf of a free library may lead a baffled youth into a rich and useful life.

H. W. ELKINTON.

MAN AND MICROBES, by Stanhope Bayne-Jones, M.D., Professor of Bacteriology, School of Medicine and Dentistry, University of Rochester. 128 pages, plates, illustrations, 13 x 19 cms. Baltimore, The Williams & Wilkins Company, 1932. Price $1.00.

Man and Microbes is a readable book that describes the men who have had most to do with microbes and, to a degree, the microbes that have had much to do with men. Those who recall The Microbe Hunters will be reminded of the same vivid romance whereby men discovered and then, after a great deal of patience, identified bacteria. Dr. Bayne-Jones' treatment is designed to meet the need of one who wants a handy, light book on this heavy subject. It does not aim to be a reference book for the physician treating cholera vibrios. A tired business man, however, with a Staphylococcus aureus might very readily divert his mind and lessen the pain in the neck by reading this little book.

The text is well illuminated with page illustrations. Most of these have been published elsewhere but republished, however, with good effect. After a general introduction to these tiny residents of this planet, one is given the picture of the good as well as the evil done by bacteria. In fact, man should be very conscious of the great debt due to friendly germs, the useful scavengers and those countless cocci which contribute so enormously to the pleasure as well as the possibility of living. It is best not to think too much of the unfriendly germs (unless one is called upon as an expert) or else the external symptoms of the disease are sure to oblige.

The behavior of bacteria in the soil, in the air and particularly in sewage justifies the space given these activities. Whole industries are based on work of bacteria as elaborated in Chapter IV. Maybe the ferments, especially those that adjust the juice of the grape to the palate, are of most significance to the industry of politics. Butter-milk, cheese, toxins and anti-toxins all bottom on bacteria. Foods must be free from the fatal botulism, a word that connotes agony to the poi soned while it honors the Greek word for sausage.

A sharp line cannot fall between industry and agriculture or the rôle played by bacteria upon, with and through plants, insects and animals. Bacteriology is so completely involved. Judging from advertisements the tobacco industry assumes importance, yet this large culture might have been decimated if it had not been for the research of Ivanowski and Beijerinck who stopped the havoc of the mosaic disease. The toll taken by the tubercle bacilli is only passingly touched on. It is a long sad chapter in the life of men and cattle.

No book however brief would be complete without a tribute to pioneer bacteriologists. Anthony Van Leeuwenhoek merits just and first praise. Louis

Pasteur and Robert Koch are the only other two microbists of a large host of indefatigables whose pictures are shown. The book for some obscure reason is dedicated to Nan.

H. W. ELKINTON.

A TREATISE ON PHOTO-ELASTICITY, by E. G. Coker, M.A., D.Sc., F.R.S., and L. N. G. Filon, M.A., D.Sc., F.R.S. 720 pages, plates, illustrations, 18.5 x 27 cms. Cambridge, University Press, 1931. Price $17.50.

This adequate treatise on Photo-Elasticity by the well known authors, E. G. Coker and L. N. G. Filon, already distinguished by their important and pioneer contributions to this subject, fulfills a much needed publication on a subject of growing interest and serves as a foundation for research in a field combining physical optics with elasticity and stress analysis.

From Brewster's discovery in 1816, of double refraction in strained isotropic transparent materials, it is interesting to note that while the subject has gained the attention of many noted physicists until now no authoritative treatise on this subject has appeared. Important contributions have appeared by Fresnel, Newmann, Maxwell, Mach and others. In the engineering field, the application of the method to problems on stress analysis was introduced by C. Wilson, followed by Mesnager and the authors in a later period, with a subsequent considerable bibliography of contributors.

The general scope and plan of the book is excellent. With three introductory chapters on General Optical Theory, Elementary Theory of Elasticity, and the Theory of Artificial Double Refraction, the basic background of the Photo-Elastic method is completed. The remainder of the book is devoted to the applications and techniques of the methods to the solutions of complicated problems in stress analysis.

The introductory chapters on General Optical Theory and the Theory of Elasticity applied to coplanar stress are well taken in spite of existing adequate treatises, such as Love's Theory of Elasticity and numerous works on physical optics. While these chapters are somewhat specialized for the subject in hand they are sufficiently generalized and originally presented to serve as valuable contributions to these separate subjects, particularly for students interested in either optical phenomena or in the theory of elasticity.

In the chapter on General Optical Theory the classical electromagnetic theory of light for propagation in isotropic substances and in crystals is excellently presented. In the discussion of polarization a careful proof is given of the Fresnel's ellipsoid and subsequent applications are made in the discussion on rays in a crystal. Discussions follow on the refraction through a prism, the spectrometer and refraction from an isotropic into a crystalline medium. The important polarizing agents, such as the Nicols' prism, passage through crystalline plates and polarization by a pile of plates are also covered in a careful mathematical presentation. Some discussion is given on the design of glass plate polariscopes and interferometers.

The chapter on Elasticity is devoted primarily to plane stress analysis, though at the beginning the well known three-dimensional mathematical presentation of strain and stress and the stress-strain relations are given in a sufficiently comprehensive manner. Weight is given to the interpretation of the

Mohr diagram in conjunction with a discussion of the criteria of failure. The most important contribution, however, appears on the subject of isoclinic and isochromatic lines and the extension of Maxwell's curvilinear method by a simple but elegant geometrical method. Orthogonal and conformal transformations, which are particularly applicable to plane stress analysis, are discussed. Finally a graphical presentation is given for the plotting of lines of equal principal stresses, that is, for families of the constant differences and sum of the principal stresses.

The chapter on Artificial Double Refraction introduces the reader into the specialized subject of stress-optical phenomena or photo-elasticity. The stress-optical coefficient, a unit, of dimensions 10^{-13} cm²/dyne as suggested by Filon is termed the Brewster. The relative retardation of two oppositely polarized rays is, therefore, proportional to the stress T in megadynes per sq.cm., and the thickness, d, in millimeters, the dimensional proportionality constant being the Brewster. Methods of determining the stress optical coefficient C are described at length and are given for glass, the celluloids, bakelite, etc. The discussion of Photo-Elastic Dispersion is of considerable interest. The optical methods for the determination of isoclinic and isochromatic lines are included, and we find special consideration given to such subjects as optical creep in celluloids, effect of initial stress on photo-elastic observations, etc. The chapter also includes the flexure experiments of Newmann and the historical development including Newmann's strain-optical theory, corrected to Maxwell's stress-optical laws, with a discussion of Wertheim's experiments, etc. An interesting discussion of double refraction in fibrous material is included.

The remaining chapters of the book are devoted to the application of the photo-elastic method, to problems in a plane involving straight and circular boundaries, flexure of beams, stress concentration problems as for holes and cracks, and general discussions on the testing of materials and problems in structures and machines.

An outstanding feature of these remaining chapters is a parallelism of the mathematical solution of many problems solved by the photo-elastic method. Thus, in the very interesting problem of the eccentric cylinder the mathematical results of Prof. G. B. Jeffry concur closely with the photo-elastic experimental results obtained by Coker.

The application of the photo-elastic method to problems of stress concentration in engineering structures is of fundamental importance, and at present no other method can attain the accuracy of the results obtained by this means.

The photo-elastic method, however, has one outstanding and serious limitation as a generalized experimental procedure for stress analysis in that its application is limited to coplanar stress problems. It is also confined to the elastic range or rather to problems where stress is a linear function of the strain. On the other hand, in many engineering problems coplanar stress distribution results can be interpolated to three-dimensional problems. The only criticism of this work, which in the opinion of the writer is perhaps also a characteristic fault of many Cambridge publications, is the lack of a preliminary chapter giving a semi-quantitative discussion of the essential features of the subject. Such a procedure would seem of value in view of the specialized nature of the subject in the latter chapters.

On the whole the work is a remarkable contribution and will prove of great value to physicists and engineers. The work undoubtedly will stimulate further interest in physical optics combined with stress analysis, and the advancement of photo-elastic laboratories throughout the world.

R. EKSERGIAN.

RECEUIL D'EXPOSÉS SUR LES ONDES ET CORPUSCULES, par Louis de Broglie, Maître de Conférences a la Sorbonne, Laureat du prix Nobel de Physique, 1929. 81 pages, 15 × 24 cms., paper. Paris, Librairie Scientifique Hermann et Cie., 1930. Price 20 francs.

The extraordinary activities, analytical and experimental, which have been proceeding during recent years in the revision of the fundamental laws of physical science may properly be said to have received their greatest impetus with the investigations of Professor Planck some thirty years ago on the true nature of the dissipation of radiant energy. That conception of "quanta," the dissipation of radiant energy, not by a continuous flow but in finite and equal quantities was a conception which in the hands of Planck assumed applicable form that has profoundly affected the progress of the long-sought theory of a monistic physics. Then came the Bohr atom with energy relationships in harmony with the quantum principle, and then the work of Heisenberg and Schroedinger and numerous others, in correlating these notions into a rational undulatory mechanics of universal applicability.

Professor Louis de Broglie, who is one of the foremost exponents in this field of activity, and recipient of the Nobel prize for physics in 1929, has collected in this volume a series of papers in which he has traced and discussed in non-mathematical terms the origin and evolution of the wave and corpuscular theories in their relation to modern atomic mechanics during the period from 1927 to 1929. The topics treated are: Modern physics and the work of Fresnel; The recent crisis in undulatory optics; As with light, electrons can interfere; Determinism and causality in contemporary physics.

It will hearten the student who is about to embark in a study of the "new physics" to have the guidance of these claryifying articles to sound procedure, and that there still remains much of the "old physics" which he will not be obliged to unlearn.

L. E. P.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS:

Report No. 420. Aircraft Speed Instruments, by K. Hilding Beij, 59 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1932.

This report presents a concise survey of the measurement of air speed and ground speed on board aircraft. Special attention is paid to the Pitot-static air-speed meter which is the standard in the United States for airplanes. Air-speed meters of the rotating vane type are also discussed in considerable detail on account of their value as flight test instruments and as service instruments for airships. Methods of ground-speed measurement are treated briefly, with references to the more important instruments. A bibliography on air-speed measurement concludes the report.

Report No. 425. The Effect of Nozzle Design and Operating Conditions on the Atomization and Distribution of Fuel Sprays, by Dana W. Lee. 19 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1932.

The atomization and distribution characteristics of fuel sprays from automatic injection valves for compression-ignition engines were determined by catching the fuel drops on smoked-glass plates, and then measuring and counting the impressions made in the lampblack. The experiments were made in an air-tight chamber in which the air density was raised to values corresponding to engine conditions.

The effects of the jet velocity, chamber-air density, orifice diameter, and the orifice length-diameter ratio on the fineness and uniformity of the atomization and on the distribution of the fuel in sprays from plain cylindrical nozzles were determined. The atomization and distribution characteristics of sprays from valves having spirally grooved stems, of sprays produced by the impinging of two fuel jets, and of sprays produced by a fuel jet striking a metal lip were also measured and compared with those of sprays from the plain nozzles.

It was found that each spray is composed of several million drops whose diameters range from less than 0.00025 inch to 0.005 inch, and sometimes to 0.010 inch. The experiments indicated that with a given fuel the fineness and uniformity of the atomization increase with an increase in the jet velocity, and with a decrease in the orifice diameter. Orifice length-diameter ratio and chamber-air density had no decided effect on the spray atomization. Centrifugal-type sprays, impinging-jet sprays, and sprays formed by a jet striking a metal lip were found to have no better atomization than sprays from plain nozzles, provided that the jet velocity was the same, but the distribution of the fuel within these sprays was found to be much better than for plain sprays.

Report No. 426. The Effect of Humidity on Engine Power at Altitude, by D. B. Brooks and E. A. Garlock, 9 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1932.

From tests made in the altitude chamber of the Bureau of Standards, it was found that the effect of humidity on engine power is the same at altitudes up to 25,000 feet as at sea level. Earlier tests on automotive engines, made under sea-level conditions, showed that water vapor acts as an inert diluent, reducing engine power in proportion to the amount of vapor present.

By combining the effects of atmospheric pressure, temperature, and humidity, it is shown that the indicated power obtainable from an engine is proportional to its mass rate of consumption of oxygen. This has led the National Advisory Committee for Aeronautics to adopt a standard basis for the correction of engine performance, in which the effect of humidity is included.

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An Introduction to Physical Science, by Carl W. Miller, 403 pages, illustrations, tables, 14.5 × 22 cms. New York, John Wiley & Sons, Inc., London, Chapman & Hall, Ltd., 1932. Price $3.00.

Encyclopedie Photometrique, Troisieme Section, Photometrie visuelle, Tome II, Etalons Photometriques, par Pierre Fleury, 122 pages, tables, illustrations, 16 × 24.5 cms. Editions de la Revue d'Optique theorique et instrumentale, 1932.

Chemical Analysis by X-Rays and Its Applications, by Georg von Hevesy, 333 pages, plates, tables, illustrations, 15.5 × 23.5 cms. New York, McGraw-Hill Book Company, Inc., 1932. Price $3.00.

National Research Council, Bulletin No. 85, Physics of the Earth—V. Oceanography, prepared under the auspices of the Subsidiary Committee on Oceanography, 581 pages, illustrations, tables, 17 × 25 cms. Washington, National Academy of Sciences, 1932. Price $5.00. Transactions of the American Geophysical Union Thirteenth Annual Meeting, April 28 and 29, 1932. 401 pages, illustrations, tables, 17 × 24.5 cms. Washington, National Academy of Sciences, 1932.

National Advisory Committee for Aeronautics, Seventeenth Annual Report, 1931, including Technical Reports nos. 365 to 400, 722 pages, illustrations, tables, 24 × 30 cms. Washington, Government Printing Office, 1932. Price $3.00.

U. S. Department of Commerce, Bureau of Mines, Mineral Resources of the United States, 1929, Part II—Nonmetals, 858 pages, tables, 15 × 24 cms. Washington, Government Printing Office, 1932. Bulletin 350, Contributions to the Data on Theoretical Metallurgy, 1, The Entropies of Inorganic Substances, by K. K. Kelley, 63 pages, tables, 15 × 23 cms. Bulletin 354, The Ignition of Fire Damp by Explosives, a study of the process of Ignition by the Schlieren Method, by W. C. F. Shepherd, 89 pages, illustrations, tables, 15 × 23 cms. Bulletin 356, Sampling and Estimation of Ore Deposits, by Chas. F. Jackson and John B. Knaebel, 155 pages, tables, charts, 15 × 23 cms. Bulletin 358, Rubber-Sheathed Trailing Cables, by L. C. Ilsley, A. B. Hooker, and E. J. Coggeshall, 53 pages, tables, illustrations, 15 × 23 cms. Mine Report, Gold, Silver, Copper, Lead and Zinc in Utah, by C. N. Gerry and Paul Luff, 54 pages, tables, 15 × 23 cms. Mine Report, Gold, Silver, Copper, Lead and Zinc in Idaho and Washington in 1930, by C. N. Gerry and T. H. Miller, 677 pages, tables, 15 × 23 cms., 6 pamphlets. Washington, Government Printing Office, 1932.

Yearbook of Railroad Information, 1932 edition, 96 pages, charts, illustrations, 10.5 × 15.5 cms. New York, Committee on Public Relations of the Eastern Railroads, 1932.

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Iowa State College of Agriculture and Mechanic Arts, Official Publication No. 45, Loads on Pipe in Wide Ditches, by W. J. Schlick, 47 pages, diagrams, illustrations, 15 × 23 cms. Ames, Iowa State College, 1932.

National Advisory Committee for Aeronautics, Technical Notes, No. 424, Preliminary Photomicrographic Studies of Fuel Sprays, by Dana W. Lee and Robert C. Spencer, Langley Memorial Aeronautical Laboratory, 7 pages, illustrations, 19 × 26 cms. Washington, Committee, 1932. No. 425, Methods of Visually Determining the Air Flow Around Airplanes, by Melvin N. Gough and Ernest Johnson, Langley Memorial Aeronautical Laboratory, 7 pages, figures, 19 × 26 cms. Washington, Committee, 1932. No. 426, Comparative Performance of a Powerplus Vane-Type Supercharger and an N. A. C. A. Roots-Type Supercharger, by Oscar W. Schey and Herman H. Ellerbrock, Jr., Langley Memorial Aeronautical Laboratory, 14 pages, figures, tables, 19 × 26 cms. Washington, Committee, 1932.

CURRENT TOPICS.

Frozen Orange Juice—A Problem.—(*Ind. and Eng. Chem.*, **24**, 665.) Not much more than a year ago one or more dairy chains announced their intention to supply frozen orange juice to customers. This they started to do in certain localities but its distribution has not yet been undertaken universally. Two seemingly logical reasons were put forward to explain why this project had not been adopted more widely. One was the comparatively low prices for oranges in even the more distant markets and the other—probably the more correct—the fact that the methods for preserving the juice are still short of the perfection stage.

Some idea as to just how difficult it is to permanently preserve orange juice in its natural state is given by M. A. Jaslyn. Complex changes rapidly take place after extraction of the juice from the fruit. These changes may be of three kinds: Those due to living organisms, easily prevented by pasteurization; those due to enzymes only partially controlled by pasteurization; and those due to oxidation and chemical reactions between the normal constituents of the juice. Some idea of the difficulties confronting the workers on orange juice preservation can be secured from the following brief list of varied problems.

Although unpasteurized orange juice stored at 32° F. will maintain its color, it loses its flavor and develops a stale, disagreeable taste.

Even frozen orange juice can lose its flavor if precautions against oxidation are not taken.

Juice from immature fruit is apt to become objectionably stale in flavor while that from overmature fruit tends to become flat in storage.

Not every variety of orange gives juice suitable for preserving. In California the Valencia is superior to the Navel. In Florida there is a decided advantage in using only one or two varieties which can be depended upon for uniformity in quality of the juice. Florida oranges are generally higher in sugar content, lower in acid and not so highly colored nor so fully flavored as similar varieties grown in California.

Juice extracted from tree-ripened oranges shortly after picking is superior to that extracted from oranges held in storage.

The flavor of orange juice is markedly impaired by even small quantities of copper and iron salts, as well as other metals in solution.

Aluminum and stainless steels are superior to other metals for the handling of orange juice and nickel may be satisfactory under certain conditions. Tin, tin-plated copper, nickel-plated copper or the nickel-copper alloys have not been found satisfactory.

The freezing of orange juice usually causes the pulp to settle out upon thawing, whereas it remains suspended under ordinary conditions.

Up to the present, the most satisfactory product has been obtained with orange juice extracted with a minimum of metallic contamination, under sanitary conditions from sound, clean, mature, tree-ripened fruit containing little or no oil from the peel and the minimum albedo; completely deaërated after straining to remove coarse pieces of pulp and seed; packed, preferably under vacuum or in an inert gas in air-tight liquid-tight containers; and rapidly frozen after extraction.

C.

THE FRANKLIN INSTITUTE

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